Institute of Water Research
Annual Technical Report
FY 2014

Introduction

The Institute of Water Research (IWR) at Michigan State University (MSU) continuously provides timely information for addressing contemporary land and water resource issues through coordinated multidisciplinary efforts using advanced information and networking systems. The IWR endeavors to strengthen MSU's efforts in nontraditional education, outreach, and interdisciplinary studies utilizing available advanced technology, and partnerships with local, state, regional, and federal organizations and individuals. Activities include coordinating education and training programs on surface and ground water protection, land use and watershed management, and many others. We also encourage accessing our web site which offers a more comprehensive resource on IWR activities, goals, and accomplishments: http://www.iwr.msu.edu.

The Institute has increasingly recognized the acute need and effort for multi-disciplinary research to achieve better water management and improved water quality. This effort involves the integration of research, data, and knowledge with the application of models and geographic information systems (GIS) to produce spatial decision support systems (SDSS). These geospatial decision support systems provide an analytical framework and research data via the web to assist individuals and local and state government agencies make wise resource decisions. The Institute has also increasingly become a catalyst for region wide decision-making support in partnership with other states in EPA Region 5 using state-of-the-art decision support systems.

The Institute works closely with the MSU Cooperative Extension Service to conduct outreach and education. Outreach activities are detailed in the Information Dissemination section of this report. USGS support of this Institute as well as others in the region enhances the Institute credibility and facilitates partnerships with other federal agencies, universities, and local and state government agencies. The Institute also provides important support to MSU-WATER, a major university initiative dealing with urban storm water issues with funding from the university Vice President for Finance. A member of the Institute's staff works half-time in facilitating MSU-WATER activities so the Institute enjoys a close linkage with this project. The following provides a more detailed explanation of the Institute's general philosophy and approach in defining its program areas and responsibilities.

General Statement

To deal successfully with the emergence of water resource issues unique to the 21st century, transformation of our knowledge and understanding of water for the protection, conservation, and management of water resources is imperative. Radically innovative approaches involving our best scientific knowledge, extensive spatial databases, and "intelligent" tools that visualize wise resource management and conservation in a single holistic system are likewise imperative. Finally, holistic system analysis and understanding requires a strong and integrated multi-disciplinary framework.

Research Program Introduction

The management of water resources, appropriate policies, and data acquisition and modeling continue to be at the forefront of the State, Regional, and National Legislatures agenda and numerous environmental and agricultural organizations. Our contribution to informing the debate involved numerous meetings, personal discussions, and most importantly, the enhancement of web-based information to aid in the informed decision-making process.

Unique Capabilities: Decision Support Systems as the Nexus
IWR, with its “extended research family,” is exceptionally well-positioned to integrate research conducted within each of the three principal water research domains: hydrologic sciences, water policy, and aquatic ecosystems. Integrated decision support both reflects and forms the nexus of these three research domains. Expanding web accessibility to the decision support system nexus (formed by the intersection of the three research domains) will facilitate broad distribution of science-based research produced in these domains. A special emphasis is being placed on facilitation of science-based natural resource state and national policy evolution. Fundamentally we are addressing the Coupled Human and Natural System (CHANS).

The Institute’s extensive experience in regional and national networking provides exceptional opportunities for assembling multi-agency funding to support interdisciplinary water research projects and multi-university partnerships.

Using a Multi-Disciplinary Framework
Using a multi-disciplinary framework facilitates dynamic applications of information to create geospatial, place-based strategies, including watershed management tools, to optimize economic benefits and assure long-term sustainability of valuable water resources. New information technologies including GIS and computational analysis, enhanced human/machine interfaces that drive better information distribution, and access to extensive real-time environmental datasets make a new “intelligent reality” possible. This is our way of addressing the "CHANS." Effective watershed management requires integration of theory, data, simulation models, and expert judgment to solve practical problems. Geospatial decision support systems meet these requirements with the capacity to assess and present information geographically, or spatially, through an interface with a geographic information system (GIS). Through the integration of databases, simulation models, and user interfaces, these systems are designed to assist decision makers in evaluating the economic and environmental impacts of various watershed management alternatives

The ultimate goal of these new imperatives is to guide sustainable water use plus secure and protect the future of water quality and supplies in the Great Lakes Basin, across the country and the world—with management strategies based on an understanding of the uniqueness of each watershed.

Modeling the Impacts of Chicago River on Lake Michigan: Dynamics of Dissolved Oxygen, BOD, Suspended Solids, Chloride and Temperature in the Nearshore Region

Basic Information

Title:	Modeling the Impacts of Chicago River on Lake Michigan: Dynamics of Dissolved Oxygen, BOD, Suspended Solids, Chloride and Temperature in the Nearshore Region
Project Number:	2012MI219S
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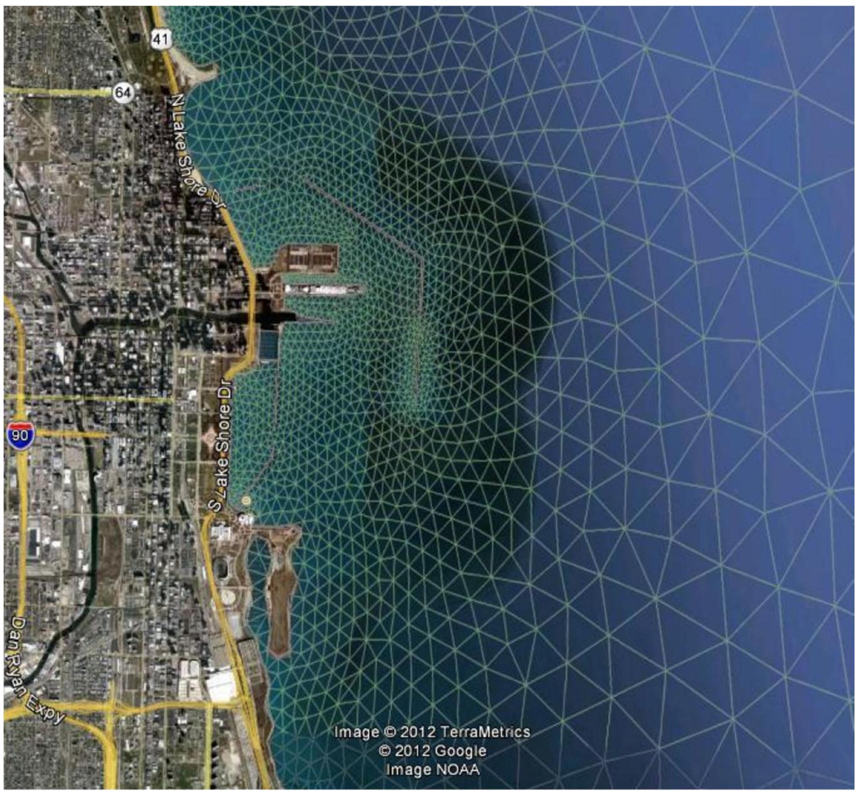
Descriptors:	Chicago River on Lake Michigan: Dynamics of Dissolved Oxygen, BOD, Suspended Solids, Chloride and Temperature
Principal Investigators:	Jon Bartholic, Phanikumar S Mantha

Publications

1. Phanikumar, Mantha S., Meredith Nevers, and Richard Whitman. 2013. Modeling The Effects Of Hydrologic Separation On The Chicago Area Waterway System On Water Quality In Lake Michigan, 105 pgs.
2. N/A

MODELING THE EFFECTS OF HYDROLOGIC SEPARATION ON THE CHICAGO AREA WATERWAY SYSTEM ON WATER QUALITY IN LAKE MICHIGAN



Final Project Report

September, 2013

TECHNICAL REPORT

Modeling the Effects of Hydrologic Separation on the Chicago Area Waterway System on Water Quality in Lake Michigan

SUBMITTED TO

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Modeling the Effects of Hydrologic Separation on the Chicago Area Waterway System on Water Quality in Lake Michigan

Summary

In this project, we have used advanced hydrodynamic and water quality models to assess the impact of discharge from riverine sources on the nearshore water quality at locations in the southwest tip of Lake Michigan. The objectives of this project were to: 1) Simulate the coupled physical and biogeochemical processes that affect nearshore water quality off the Chicago lake-front; 2) Simulate baseline conditions and seasonal variation in the background concentrations of water quality variables lake-wide as well as in the nearshore region using a calibrated numerical model; 3) Determine the impact of removing river controls on the Chicago River and the Chicago Area Waterway System (CAWS) on nearshore water quality in Lake Michigan. The main riverine discharges (outfalls) considered in this study include the North Shore Channel, Chicago River, Calumet River, Indiana Harbor Canal, and Burns Ditch. The flow rate and concentration of water quality variables at the outfall locations were determined using a watershed model, DUFLOW, which simulated water quality conditions in the CAWS under a mid-system hydrologic separation scenario [GLMRIS Report, 2013].

Concentrations of nutrients, indicator bacteria and other water quality variables were simulated using a water quality model coupled to the FVCOM hydrodynamic model. The numerical models used an unstructured (triangular) grid with variable resolution in the nearshore

and offshore locations to resolve both small-scale and large-scale processes. In addition to simulating hydrodynamics (currents), the numerical models simulated ten water quality variables. The variables that were modeled explicitly by the water quality model were: 1) Dissolved oxygen, 2) Biochemical oxygen demand, 3) Phytoplankton, 4) Nitrate and Nitrite Nitrogen, 5) Ammonia Nitrogen, 6) Organic Nitrogen, 7) Organic Phosphorous, 8) Inorganic Phosphorous (or ortho-phosphate), 9) Fecal indicator bacteria (*E. coli*), and 10) Chloride.

We found that nutrient inputs from the outfalls that are part of the Chicago area waterway system can significantly increase the primary productivity (algal biomass) in the nearshore region. However, contaminant plumes are transported and dissipated quickly in the nearshore region by the predominantly along-shore currents and turbulent mixing with offshore waters. Simulations recreating the September, 2008 storm event indicated that concentrations of fecal indicator bacteria and ortho-phosphorous at water intakes could exceed candidate benchmarks during extreme weather events. However, the concentration of contaminants in the nearshore region reduced to background levels in about 7-10 days. As expected, the model predicted that the effect of discharge from the outfalls is more significant (in terms of persistence as well as peak values) at intakes that are closer to the major outfalls.

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Chapter 1: Introduction

1.1 Problem description

The Chicago Area Waterway System (CAWS) is composed of over 100 miles of rivers and canals which include the North Shore Channel, the North Branch of the Chicago River, the Chicago River, the South Branch of the Chicago River, the Chicago sanitary and Ship Canal, the Calumet River, the Little Calumet River, and the Grand Calumet River. The canals were constructed between 1900 and 1922 and they divert the flow away from Lake Michigan into River Mississippi. The principal purpose was to protect the drinking water supply by directing waste away from Lake Michigan and to provide a navigable waterway linking River Mississippi with the Great Lakes. However, this hydrologic link connecting the Mississippi river basin with the Great Lakes has significant ecological impacts in addition to economic benefits, as is being shown by the problem with transfer of aquatic invasive species.

Construction of hydrologic separation barriers on the Calumet-Sag Channel and the Chicago Sanitary and Ship Canal will result in the treated and untreated wastewater constantly discharging into Lake Michigan. The higher discharge from North Shore Channel, Chicago River and Calumet River into Lake Michigan is expected to increase the nutrient levels in the nearshore region of Lake Michigan. Higher nutrient inputs as a result of higher discharge from Chicago River could adversely affect the water quality at drinking water intakes for communities in the NE Illinois or NW Indiana. In this study, we have used numerical models tested against hydrodynamic and water quality data collected in the field to determine the impact that removing river controls on the Chicago River will have on water quality off the shore of the Chicago metro region.

Discharge from the CAWS enters Lake Michigan at several points. The Chicago Sanitary and Ship canal drain into the Chicago River and the North Shore Canal (Wilmette near Evanston), while the Calumet-Sag channel flows into the Calumet River. In this project, we have included the flow from the North Shore Channel, the Chicago River, the Calumet River, and the Indiana Harbor canal. In addition, we have also included the flow from the Burns Waterway (Burns Ditch) that is connected to the Little Calumet river system. The important river systems, their discharge points and the state boundaries are included in Figure 1.1 shown below.

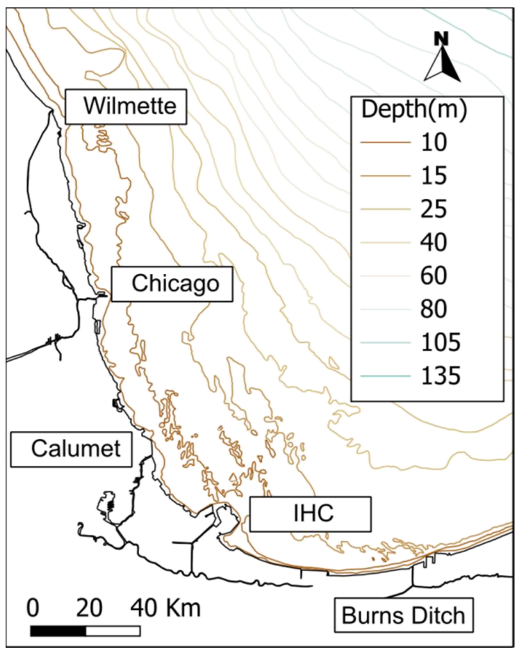

Figure 1.1 Map showing some of the major rivers and outfalls that discharge into the southern part of Lake Michigan (IHC: Indiana Harbor Canal).

Although numerous studies have examined the impact of river system redirection and its impacts on water quality in the canals and channels of the CAWS [*Melching*, 2006; *Shreshta and Melching*, 2003], this is the first study of its kind in that it examined the impact of high effluent discharge rates from the CAWS discharge points on water quality off shore of Chicago and nearby areas. The objectives of this study were to:

1. Simulate the coupled physical - biogeochemical processes that affect nearshore water quality off the Chicago lake-front.

2. Simulate baseline conditions and seasonal variations in the background concentrations of water quality variables lake-wide as well as in the nearshore region by using calibrated numerical models.

3. Evaluate the impact on nearshore water quality if the lakefront controlling works, including Wilmette Pumping Station, Chicago River Controlling Works, and the O'Brien Lock and Dam were removed and new physical barriers were constructed on the CSSC and Cal-Sag Channel to separate the Great Lakes and the Mississippi River basins.

1.2 Scope of the project

Biogeochemical processes that affect the concentrations of water quality parameters in the nearshore region of a large freshwater lake such as Lake Michigan are highly complex and involve processes occurring at multiple time and space scales. Several studies of varying complexity have attempted to study this problem in the past [*Chen et al*., 2002, *Ji et al*., 2002, *Luo et al.* 2012]. In this study, the principal focus was on the impact of discharge from the river outfalls on water quality in the nearshore region of Lake Michigan in NE Illinois and NW Indiana. Therefore, processes that impact the long-term variability in the water quality are beyond the scope of this study.

Some of the major assumptions/limitations that are implicit in the modeling exercise are listed below:

a. The principal sources of pollution are storm runoff and sanitary flows from watersheds that contribute to the canals and channels that form the Chicago Area Waterway System.

b. Sediment resuspension as a result of storm-generated waves is not included in the numerical model.

c. Non-point sources such as distributed sources along the beach and ground water seepage are also not considered in the model.

In addition, several simplifications to the complex interactions between different water quality variables are made and have been discussed in greater detail in the chapter describing the numerical water-quality model used in the study.

1.3 Structure of the report

The report has been divided into five chapters. The problem description, objectives and the scope of the project are covered in Chapter 1: Introduction. Chapter 2 introduces the numerical models and provides a detail description of the assumptions and simplifications made in order to arrive at the equations solved by the models. The numerical models are tested against hydrodynamic and water quality data collected during a field study conducted in August 2012. Chapter 3 presents results from these validation tests. Using results from the watershed model [*Melching*, 2006], the nearshore water quality model was used to simulate several scenarios that will be used to assess the impact of discharges from the CAWS on the nearshore region. The results from these simulations will be presented and analyzed in Chapter 4. Chapter 5 presents the concluding remarks.

Chapter 2: Materials and Methods

In this chapter, we present the details of the hydrodynamic and water quality models used in the present study and the methods used to test water samples, collected as part of a field study. The observed data are used to calibrate the numerical hydrodynamic and water quality models. The Finite-Volume Coastal Ocean Model (FVCOM, [*Chen et al.*, 2003]) formed the basis for the present modeling work. All the governing equations solved by the numerical models and the symbols are explained in Appendix-A. The hydrodynamic model was tested using observed current data measured using Acoustic Doppler Current Profilers (ADCPs) deployed in the nearshore region of Lake Michigan near Chicago. The water quality models were tested against observed concentrations for dissolved oxygen, chloride, nutrients, phytoplankton and temperature.

2.1 Computational mesh

The hydrodynamic and water quality equations are solved by the numerical model on the unstructured grid shown in Figure 2.1. The mesh is composed of 12,825 nodes and 23,757 triangular elements. In the vertical direction, the FVCOM model uses the terrain-following sigma-coordinate. Twenty-one sigma-levels were used to map the bathymetry in the lake and to resolve topographical features accurately. The principal sources of pollution and discharge for the Chicago area waterway system are Wilmette, Chicago River Controlling Works (CRCW), Calumet, IHC (Indiana Harbor Canal) and Burns Ditch. The locations of these outfalls are shown in Figure 2.2.

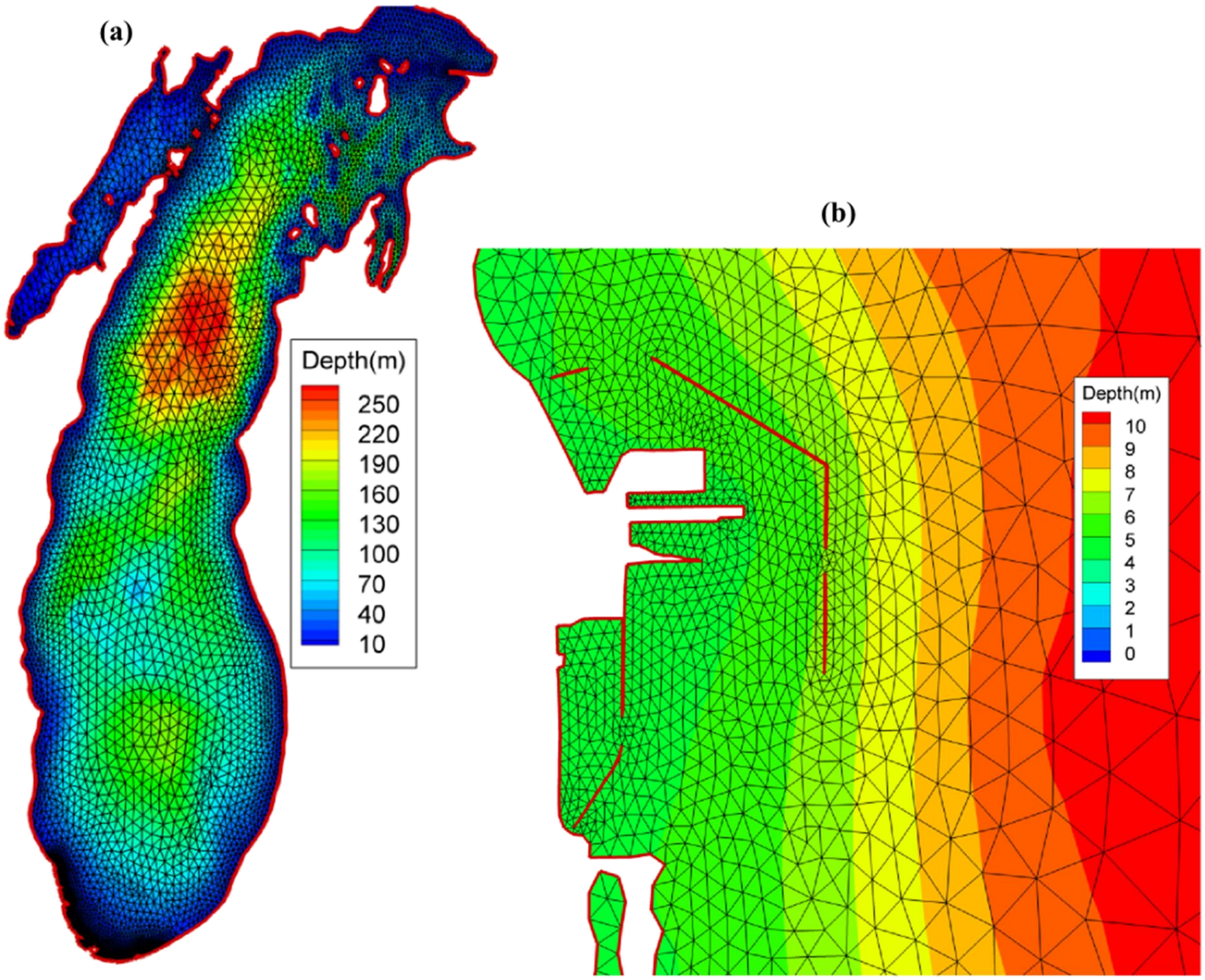

Figure 2.1 (a) The unstructured computational mesh used to resolve lake-wide circulation, (b) coastal features as described by the computational mesh near the Chicago River mouth.

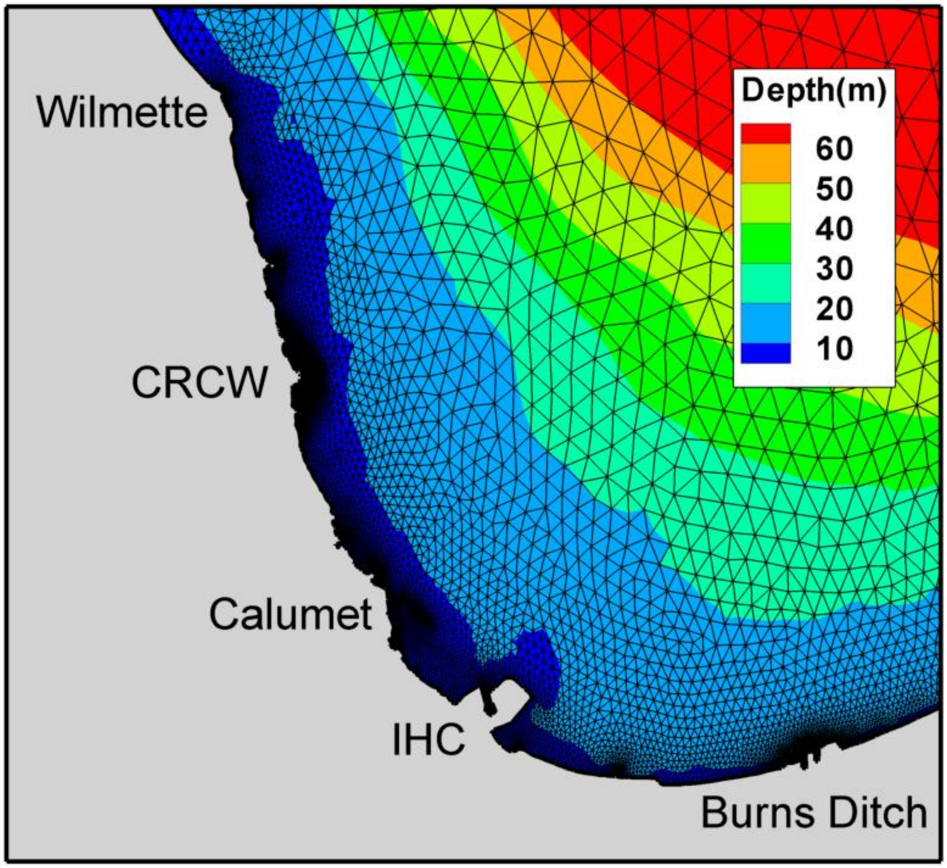

Figure 2.2 Outfalls included in the numerical model (IHC: Indiana Harbor Canal)

2.2 Field Study

A field study was conducted during the summer of 2012 to support the model testing and calibration analyses for this study. Three Acoustic Doppler Current Profilers (ADCPs) are deployed in southern Lake Michigan near Chicago. The first instrument (BBADCP in Table 2.2) is a 600 kHz Teledyne RD Instruments ADCP deployed near Chicago in approximately 20 m of water, the second instrument is a Teledyne 1000 kHz Sentinel-V ADCP and the third one is a Sontek ADCP deployed near Burns Ditch in approximately 5m of water. The laboratory methods of analysis for different water quality variables are described below. All samples were analyzed at the USGS Great Lakes Science Center (Porter, IN) and by Dr. Julie Peller, Indiana University. The approximate sampling and ADCP deployment locations are shown in Figure 2.3.

The ADCP and water sampling locations shown in Figure 2.3 are located near the southern tip of Lake Michigan and off the Chicago shoreline. Three ADCPs were deployed at location M, location S, and location V (Figure 2.3). Multiple water samples were collected in the nearshore region at multiple depths as detailed in Tables 2.1 and 2.2 and tested for Chloride, Nitrate, Sulphate, Phosphorous, Ammonia, Dissolved oxygen, Carbonaceous Biochemical Oxygen Demand (CBOD), and *E. coli* (indicator of fecal contamination in recreational waters).

2.2.1 Model testing and calibration

The numerical water quality model was tested and calibrated using data collected at the Burns Ditch outfall which is located in southern Lake Michigan. The outfall was chosen as the site for the field study due to its similarity (size and location) with the other outfalls of interest in this study (Wilmette, CRCW, Calumet, IHC). The data collected at the Burns Ditch outfall were used to provide model inputs and to test the hydrodynamic and water quality models. Background concentrations of water quality variables were estimated using samples collected at WQ2 which is in the far field of the Burns Ditch plume. It was assumed that discharge from the Burns Ditch waterway would have the greatest impact on the concentration of water quality variables at the near-field location WQ1. The comparisons at location WQ1 were used to estimate the error in model predictions and explore the parameter space for the water quality model. The final set of parameters used in the water quality model chosen provided a good estimate for all the water quality variables studied. Table 1 in Appendix A provides the parameters that were used to simulate the water quality processes. Model calibration did not include data at other water intake locations (eg. Jardine) as relevant source concentration at nearby point (riverine) and non-point sources were not adequately defined for model testing purposes.

Table 2.1 Approximate depth at which water samples were collected at locations WQ1, WQ2

Location	Surface	Mid	Bottom
Depth (ft)	2	7	13

Table 2.2 GPS location of sampling points and ADCP deployment

Name	ID	Latitude	Longitude	Apprx. depth(m)
Burns Ditch (WQ)	BD	N 41.622046	W 87.176442	NA
Plume Sampling Point (WQ)	WQ1	N 41.633164	W 87.183936	5 m
Lake Sampling Point (WQ)	WQ2	N 41.631769	W 87.193308	5 m
BBADCP (ADCP)	B	N 41.886779	W 87.542828	20m
V-ADCP (ADCP)	V	N 41.674955	W 87.196890	20 m
Sontek (ADCP)	S	N 41.631750	W 87.193308	4 m
Sentinel (ADCP, 2008)	S08	N 41.63813	W 87.18539	10 m
Monitor (ADCP,2008)	M08	N 41.71059	W 87.20996	20m
BBADCP(ADCP,2008)	B08	N 41.69717	W 87.10078	18m
NDBC Stn.	45002	N 45.3333	W 86.4297	175 m
NDBC Stn.	45007	N 42.6736	W 87.0261	160 m

TC and TOC:

Total dissolved carbon (TC) and total dissolved organic carbon (TOC) were measured using a Shimadzu Total Organic Carbon Analyzer, model TOC-5050, equipped with an ASI-550A autosampler. For the determination of dissolved organic carbon, the inorganic carbon was removed from the solution by acidification with phosphoric acid and nitrogen gas purging of the carbon dioxide that formed. The reported values were averages of 3 replicates.

Anions:

Ion analyses were performed using a Waters HPLC system, equipped with a conductivity detector. For anion separations, the IC-Pak™ Anion column was used. The mobile phase, prepared from concentrated sodium borate gluconate, was diluted with water and mixed with *n*-butanol and acetonitrile, as specified by the Waters care and use manual. A stock solution, consisting of fluoride (1 ppm), chloride (2 ppm), nitrite (4 ppm), bromide (4 ppm), nitrate (4 ppm), phosphate (6 ppm) and sulfate (4 ppm), was prepared and run prior to all the sample analyses.

Ammonia measurements (NH_3), using an ammonium ion probe:

Samples were measured either 1) within a few hours after collection, or 2) within a few days after collection (stored in the refrigerator). Water samples were treated with sodium hydroxide to raise the pH and convert the ammonium ion to ammonia gas. The probe was added to the treated water and parafilm was used to seal the container while the probe measured the ammonia gas.

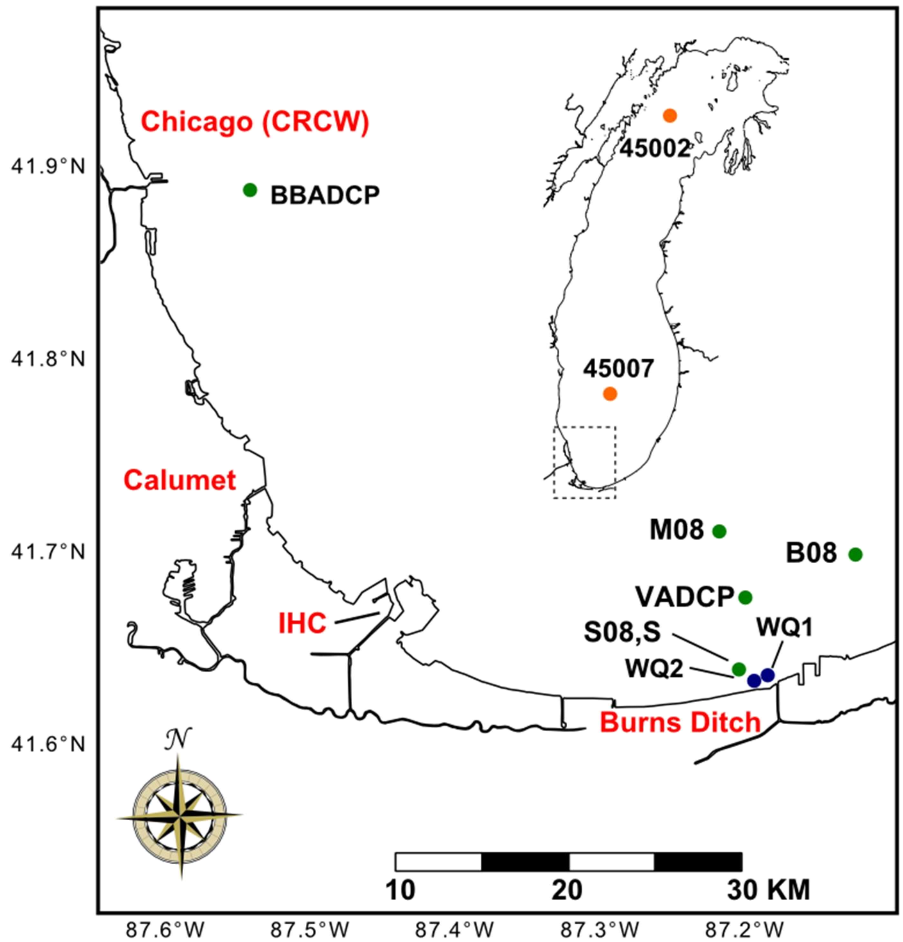

Figure 2.3 Geographical sketch showing approximate locations of sampling (WQ1 & WQ2) and ADCP deployment locations.

Chlorophyll *a*

The frozen filters were sonicated in 4 mL of 90% acetone and fine filtered in the dark. All of these solutions were run with an HPLC (High-performance liquid chromatography) method that separates the pigments, where the chlorophyll *a* elutes just before 7 minutes. Standards of chlorophyll *a* were prepared and run to quantify all the samples.

BOD analysis (5-day)

Samples were processed upon arrival to the laboratory. All samples were analyzed unseeded, lake samples were analyzed undiluted, and Burns Ditch water was analyzed undiluted and with a 2-fold dilution; distilled water (20^{o}C) was used for Burns Ditch dilution and the control. Samples and control (~325-mL) were poured into clean beakers, a crystal of Na_2SO_3 was added to each beaker, and each sample was aerated for 15 min with aeration stones connected to fish tank pumps and then allowed to rest for 30 min. After 30 min, samples were poured into 300 mL BOD bottles and analyzed for initial DO with a Pro BOD instrument (YSI incorporated, Yellow Springs, OH); care was taken to rinse the electrode between each sample. The bottles were then fitted tightly with a stopper, water sealed, and incubated at 20^{o}C in the dark for five days. After five days of incubation, the final DO of each sample was measured.

In situ analysis of DO

Dissolved oxygen for Burns Ditch was obtained from a U.S. Geological Survey gaging station (04095090) located on Burns Ditch waterway in Portage, IN (41°37'20", 87°10'33"). Dissolved oxygen for the lake samples was obtained employing a field dissolved oxygen meter (YSI incorporated, Yellow Springs, OH).

2.3 Scenarios simulated

The calibrated models were used to simulate different scenarios that are representative of current (baseline) and expected future watershed loading. The scenarios have been described in greater detail in Section 3.4. The loading from sanitary and channel discharge entering Lake Michigan in NE Indiana and NW Illinois are calculated using the DUFLOW watershed model. In all, the watershed model provided concentrations of: 1) Dissolved oxygen, 2) Biochemical Oxygen Demand (BOD), 3) Ammonia, 4) Nitrate, 5) Organic Nitrogen, 6) Inorganic Phosphorous, 7) Organic Phosphorous, 8) Fecal Coliform, and 9) Chloride. Phytoplankton concentrations were not available from the watershed model and therefore constant input concentrations of 1 mg/L were assumed at the outfalls included in the model. The concentration of fecal indicator bacteria was converted from fecal coliform to *E. coli* by assuming a 1:1 relationship [*Cude*, 2005; *Zmuda, et al.*, 2004]. The time series of the data used in the model are presented in Appendix B (Input series). The simulations were stopped and restarted during the winter months when ice-cover affects the hydrodynamics significantly. Since the hydrodynamic model did not model ice dynamics, the numerical models were stopped in October and restarted in February based on results from the simulation modeling the baseline scenario.

Chapter 3: Results

In this chapter the observations from the field study are presented along with results from the water quality and hydrodynamic numerical models. We first present the observed concentrations for the water quality variables followed by comparisons between observed and simulated results for various scenarios described in Chapter 2.Analysis and discussion of the results are presented in Chapter 4.

3.1 Observations

The observed concentrations of different water quality variables at the different water sampling locations i.e., Burns Ditch, Lake (WQ1), and Plume (WQ2) are shown in Figures 3.1 – 3.10. All concentrations are provided in mg/L which is equivalent to g/m^3.

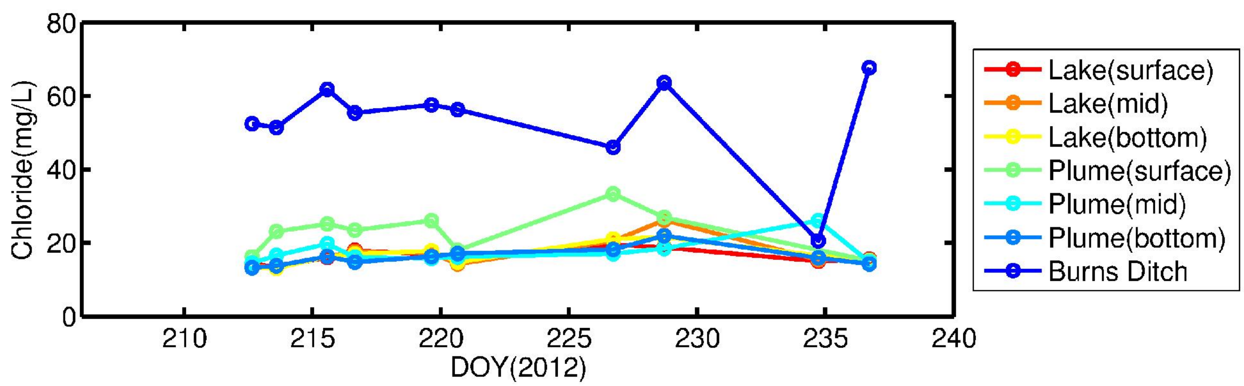

Figure 3.1 Concentration of chloride ion at water sampling locations

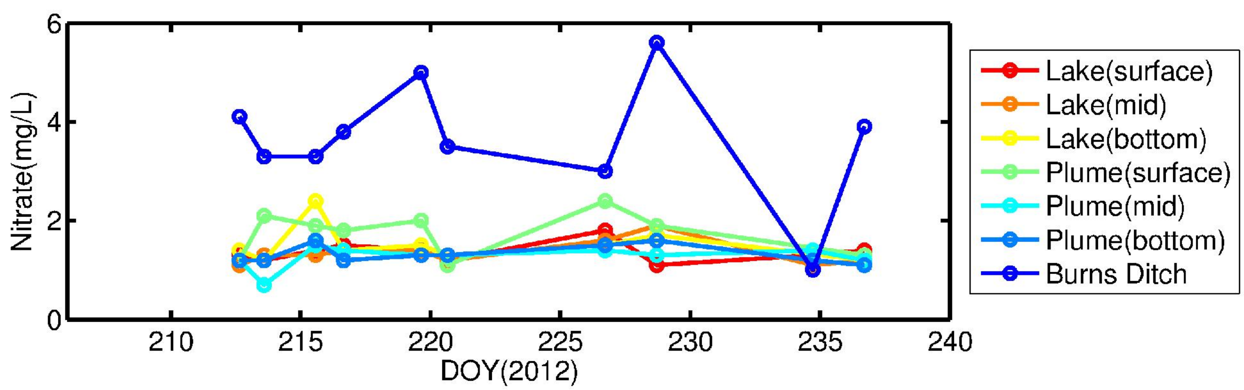

Figure 3.2 Concentration of nitrate ion at water sampling locations

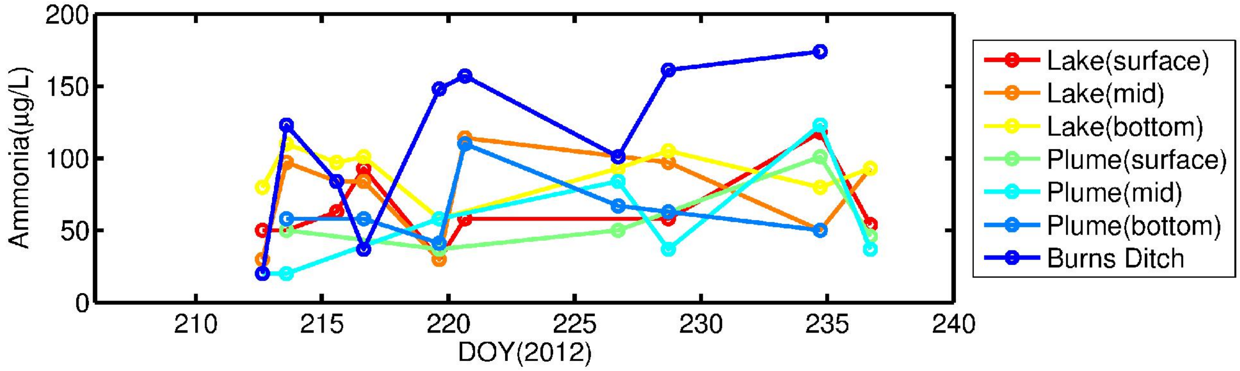

Figure 3. 3 Concentration of ammonia ion at water sampling locations

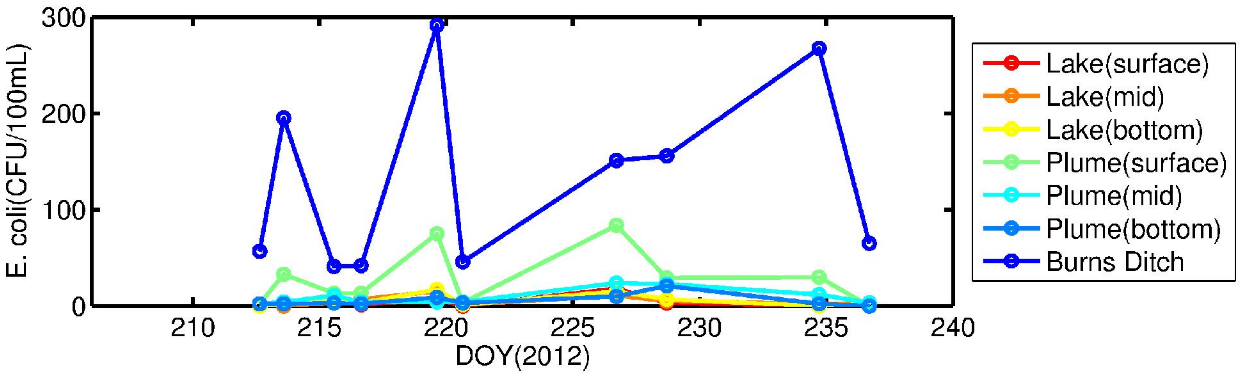

Figure 3. 4 Concentration of E. coli at water sampling locations

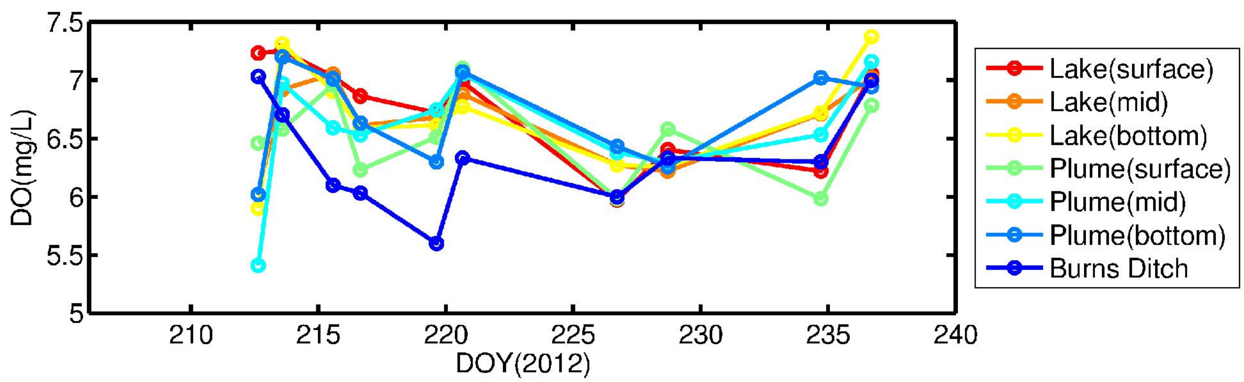

Figure 3. 5 Concentration of dissolved oxygen at water sampling locations

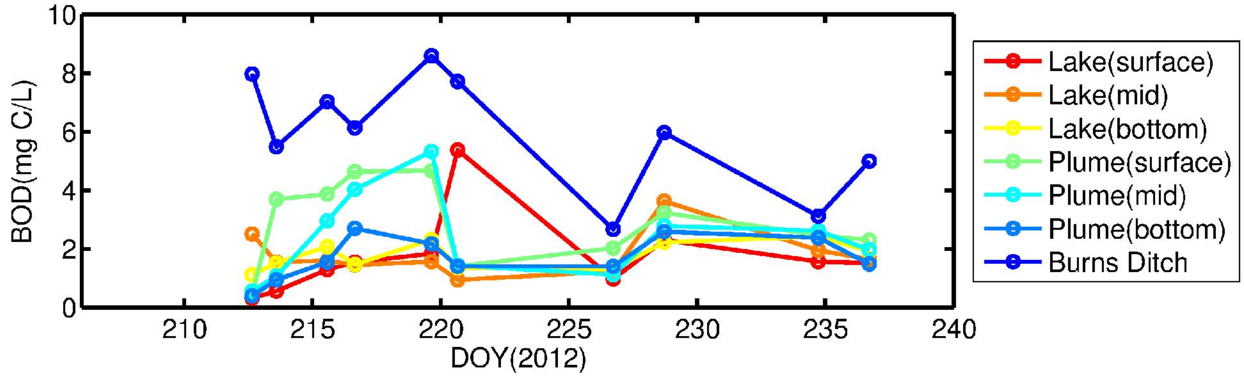

Figure 3. 6 Concentration of biological oxygen demand at water sampling locations

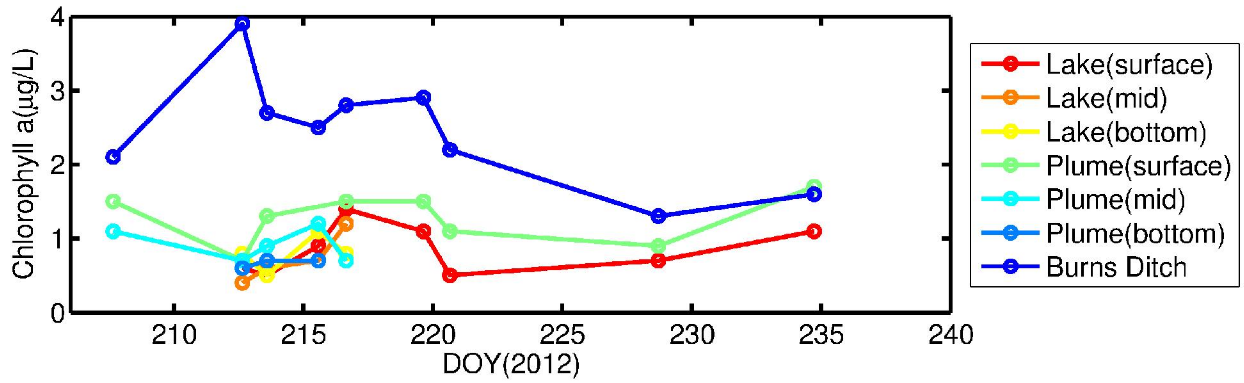

Figure 3. 7 Concentration of phytoplankton (chlorophyll a) at water sampling locations

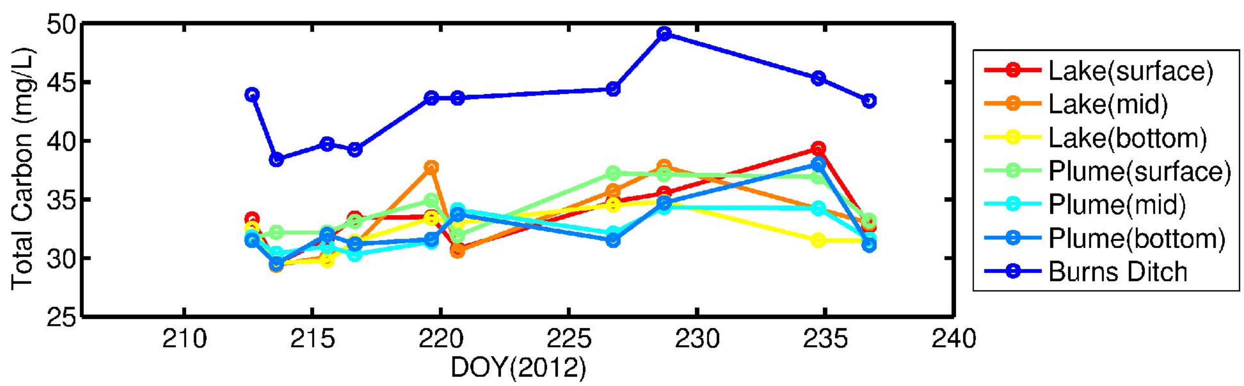

Figure 3. 8 Concentration of total carbon at water sampling locations

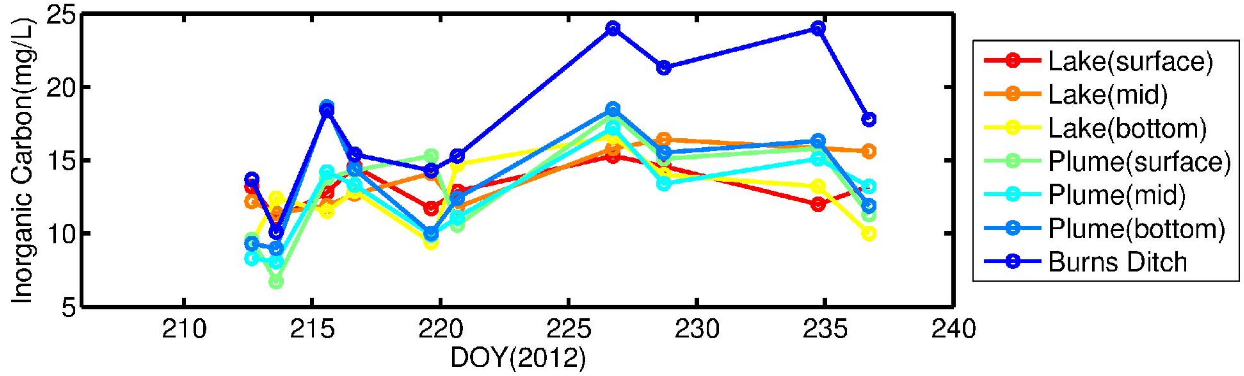

Figure 3. 9 Concentration of total inorganic carbon at water sampling locations

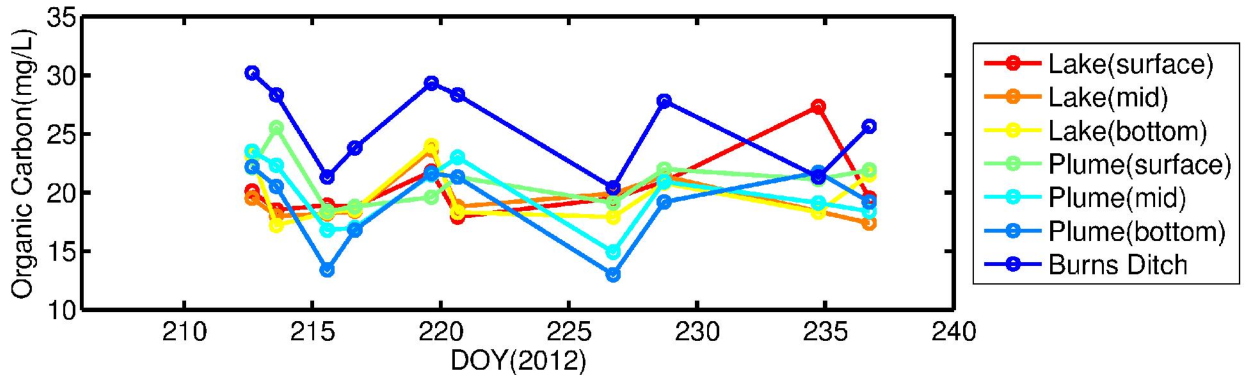

Figure 3. 10 Concentration of total organic carbon at water sampling locations

3.2 Hydrodynamic Model results

The hydrodynamic model was tested against the temperature observations from NDBC buoys moored at offshore locations in southern (#45007) and northern (#45002) Lake Michigan. Vertically-integrated velocity results from the numerical model were compared against similar ADCP observations in southern Lake Michigan collected during the 2012 field study (Figure 2.3) at locations S and B. In addition to the hydrodynamic data collected in 2012, data from an earlier study (Thupaki et al., 2010; Thupaki et al., 2013a) collected in 2008 were also compared with model results.

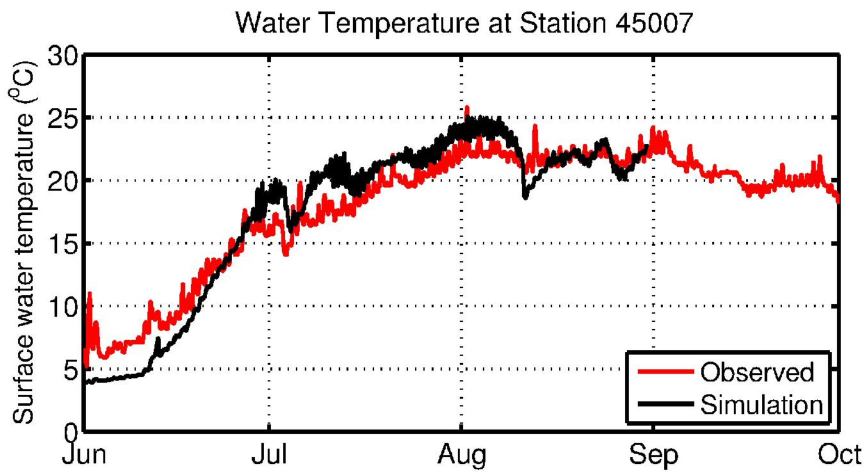

Figure 3.11 Comparison between observed surface water temperature at NDBC buoy 45007 and model results

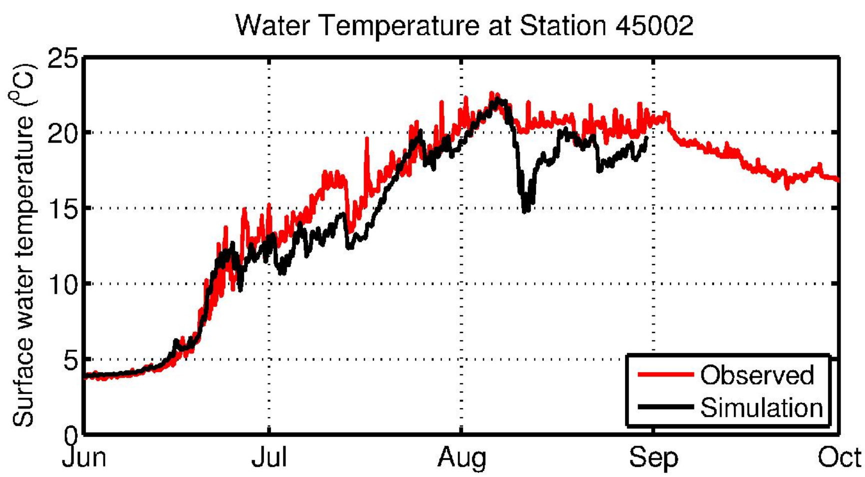

Figure 3.12 Comparison between observed surface water temperature at NDBC buoy 45002 and model results

The comparisons presented in Figures 3.11 and 3.12 show that the model is able to simulate the gradual warming of the water column during the summer months. However, some of the smaller perturbations in the surface water temperature at offshore locations are not well simulated as shown by the sudden drop in simulated temperature in mid-August.

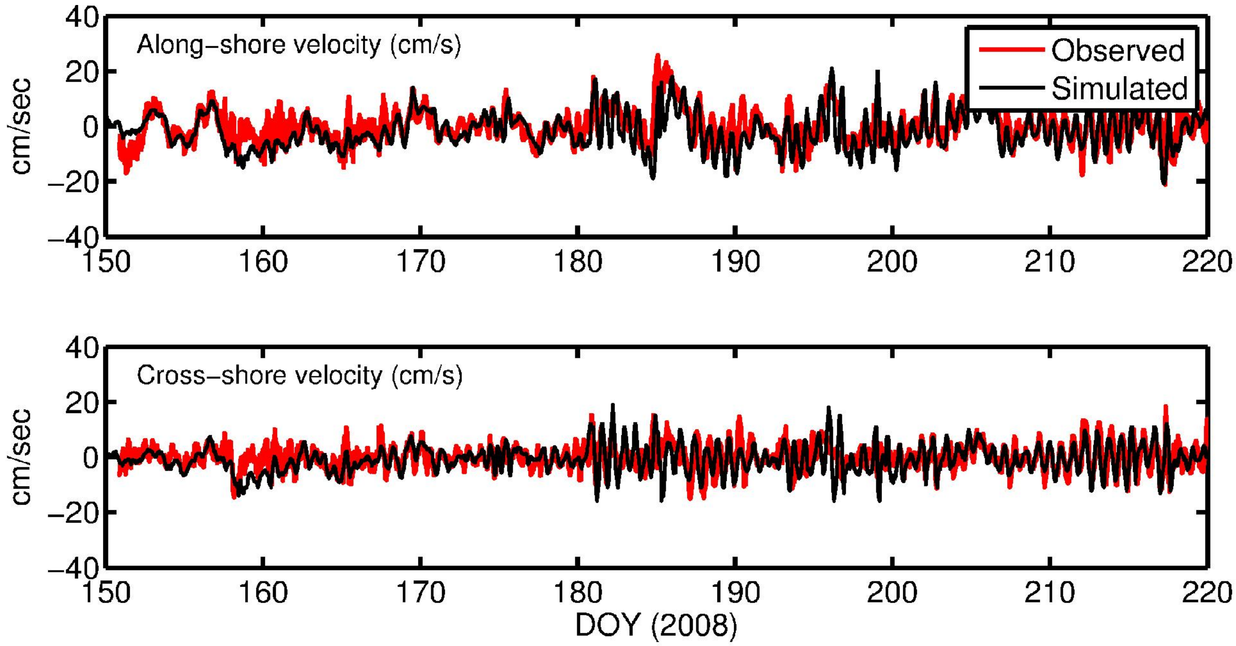

Figure 3.13 Comparisons between observed velocities in 2008 at location B08 and model results

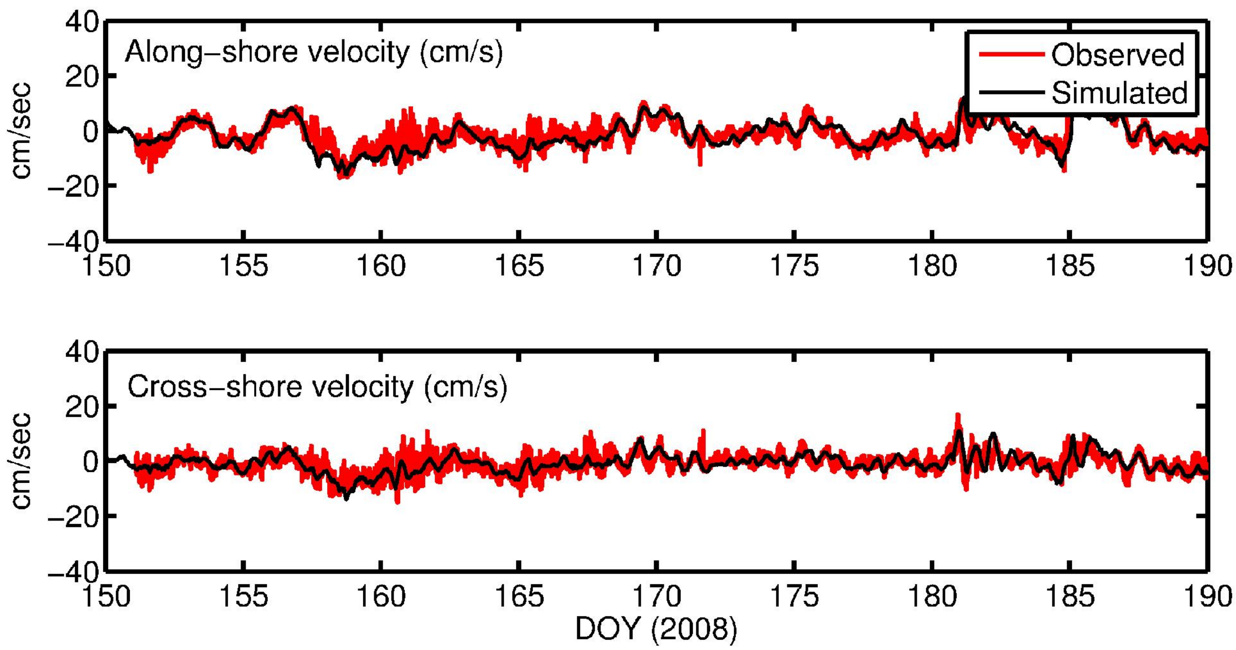

Figure 3.14 Comparisons between observed velocities in 2008 at location M08 and model results

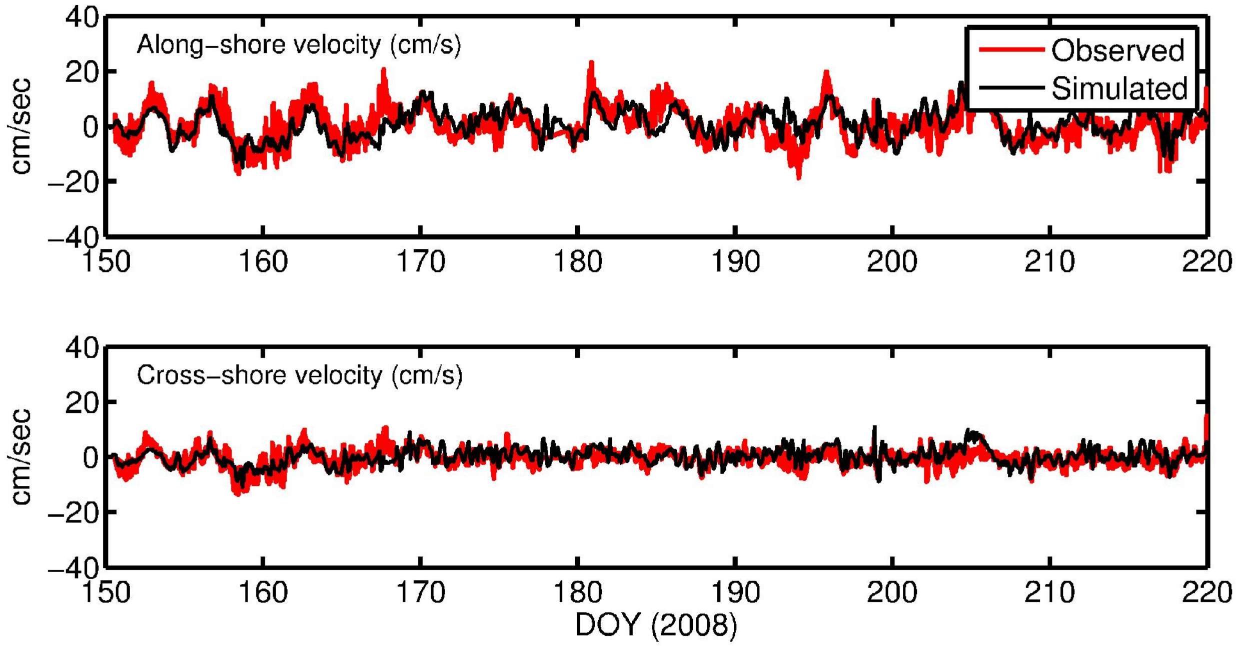

Figure 3.15 Comparisons between observed velocities in 2008 at location S08 and model results

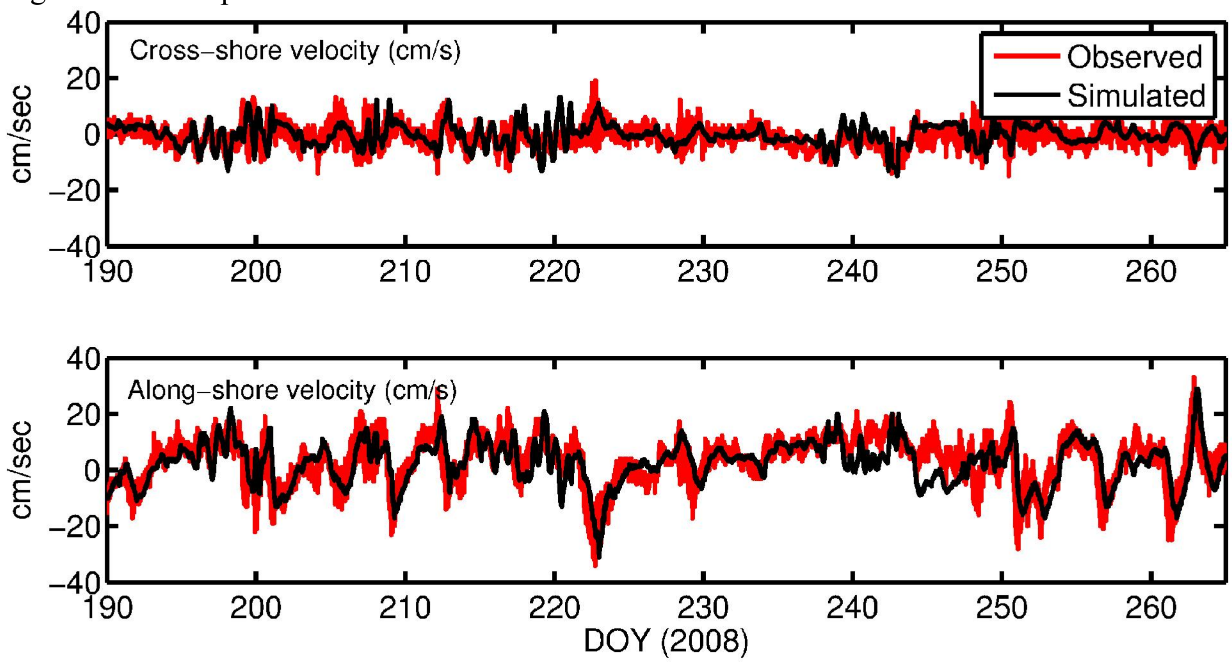

Figure 3.16 Comparisons between observed velocities in 2012 at location BBADCP and model results

3.3 Water quality model results

We calibrated the numerical water quality model using observations of Chloride, *E. coli*, Nitrate, Dissolved Oxygen, and Biochemical Oxygen Demand made during the field study in the summer of 2012. The observed (black squares) and simulated (blue solid line) values shown in the figures 17-21 are vertically averaged over the water column. Vertical variability in simulated concentrations of the water quality variables are presented by showing the maximum and minimum values in the vertical along with the vertical average. Measurements of water quality variable concentrations at location WQ2 are used to provide the background concentrations for the nearshore region. Concentrations are provided in mg/L which is equivalent to g/m^3.

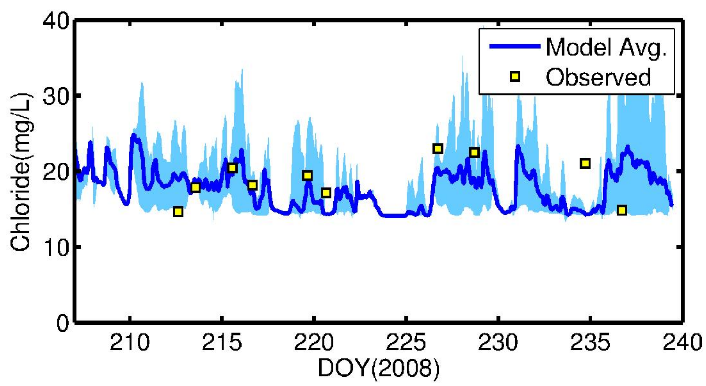

Figure 3.17 Comparison between observed and simulated values of chloride ion concentration at location WQ1

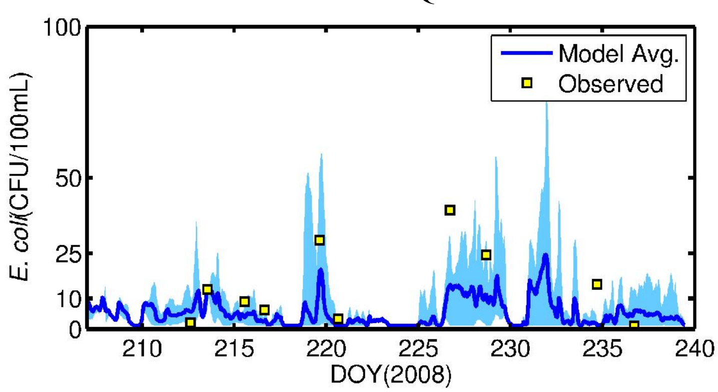

Figure 3.18 Comparison between observed and simulated values of *E. coli* concentrations at location WQ1

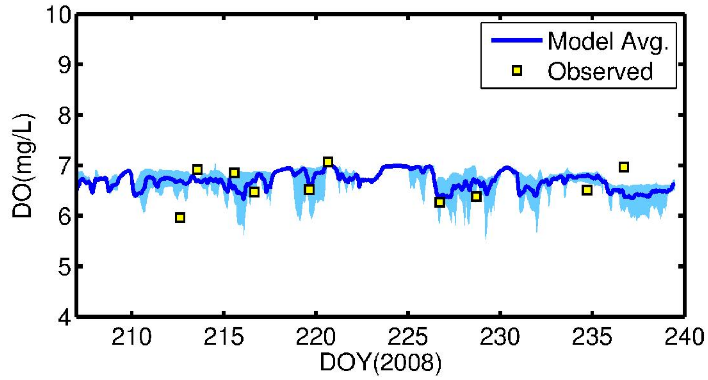

Figure 3.19 Comparison between observed and simulated values of DO concentrations at location WQ1

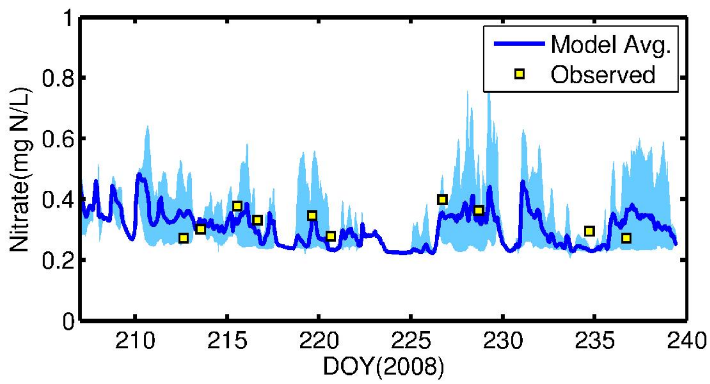

Figure 3.20 Comparison between observed and simulated values of Nitrate concentrations at location WQ1

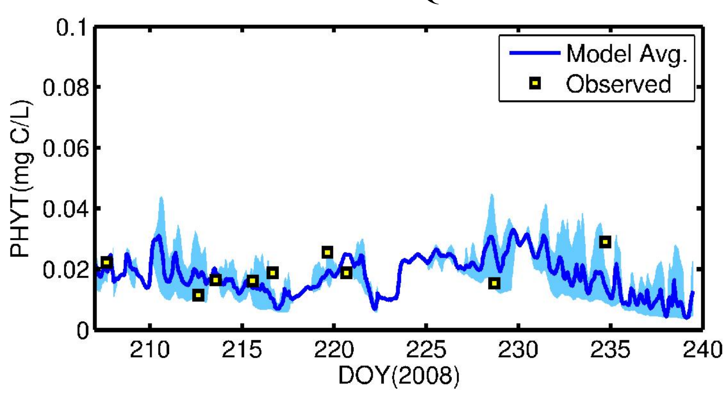

Figure 3.21 Comparison between observed and simulated values of Phytoplankton concentration at location WQ1

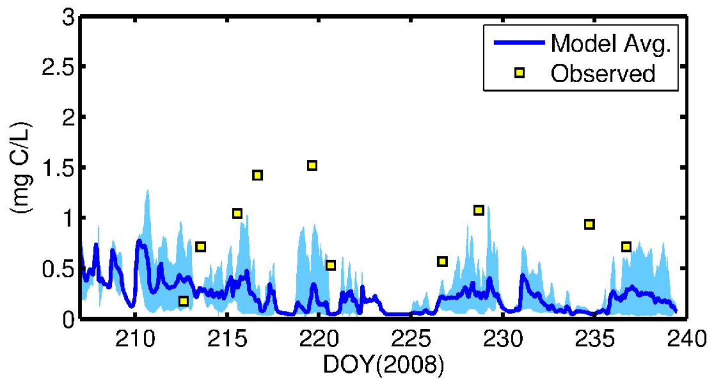

Figure 3.22 Comparison between the measured net biological oxygen demand and the model simulated carbonaceous biochemical oxygen demand. The difference between BOD and CBOD (i.e. the NBOD) is not computed by the model.

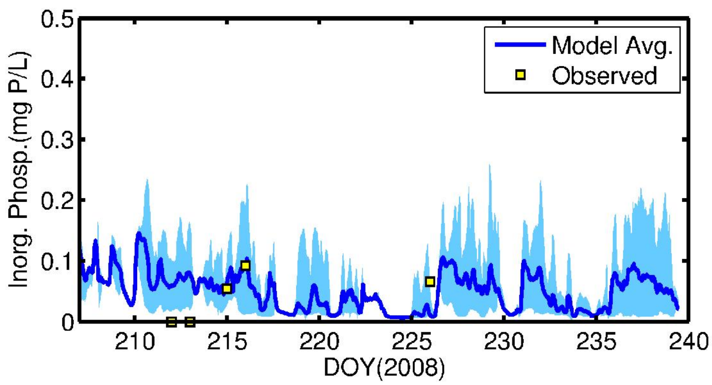

Figure 3.23 Comparison between measured and observed concentration of Inorganic Phosphorous (Phosphate ion).

The ability of the numerical model to predict transport of a tracer depends on the accuracy of the hydrodynamic model. The comparison with chloride (which acts as a tracer) shows that the model is able to simulate the mixing and transport processes that affect plume dynamics from a riverine discharge point. The models performance in the nearshore region is of particular importance since water intakes that are of importance for this study are located at or close to shore. The above comparisons with observed water quality variables provide confidence in the model's ability to describe nutrient and contaminant dynamics and allow us to test various scenarios. Table 3.1 shows where the important intakes for the City of Chicago, Gary and Evanston are located. Results, shown in figures 3.25 through 3.74, have been presented for the time series of the concentration at these locations in order to assess the impact that changes to the river control will have on water quality at the drinking water locations on the shore of Chicago.

Table 3.1 Major water intakes for this study

#	Name
1	Evanston
2	Chicago-Jardine (crib)
3	Chicago-Jardine (shore)
4	Chicago-South (crib)
5	Chicago-South (shore)
6	Hammond
7	Gary

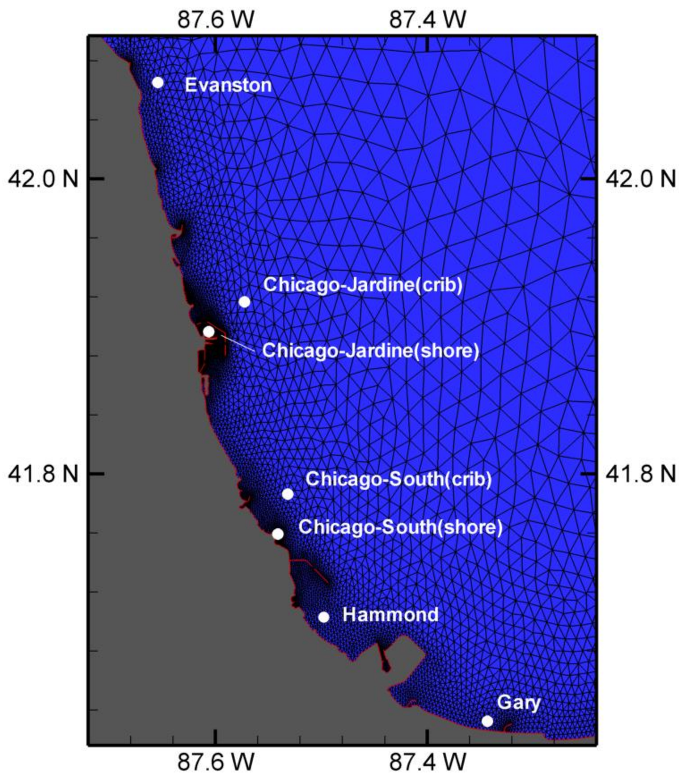

Figure 3.24 Approximate locations of major water intakes along the coastline of southern Lake Michigan

3.4 Scenario results

In this section, we present results from the numerical model for different past and potential future scenarios. In all five different scenarios have been simulated. They are:

1. **Baseline scenario**: This scenario simulates the seasonal variations in the concentrations of water quality in the nearshore region as well as over the entire lake. Meteorological forcing is based on the observations collected at the NCDC and NDBC stations located around Lake Michigan during 2008. The contaminant loadings for the Burns Ditch and Indiana Harbor Canal outfalls are based on observations. The aim of this simulation is to determine the baseline (lake-wide and nearshore) conditions in the absence of any loading from the outfalls that are part of the Chicago Area Waterway System.
2. **Continuous release (2017):** This scenario simulates the impact of year-long discharge from the outfalls on the nearshore water quality. Meteorological forcing is based on the observations collected at the NCDC and NDBC stations located around Lake Michigan during 2008. Contaminant loading for this scenario is obtained from a watershed model that simulates hydrologic processes and precipitation based on projections for 2017.
3. **Continuous release (2029):** This scenario simulates the impact of year-long discharge from the outfalls on the nearshore water quality. Meteorological forcing is based on the observations collected at the NCDC and NDBC stations located around Lake Michigan during 2008. Contaminant loading is obtained from a watershed model that simulates hydrologic conditions and precipitation based on projections for 2029.
4. **Episodic release (2017):** This scenario simulates the extreme discharge conditions based on the September storm event in 2008. The wind conditions on the lake are based on the

2008 meteorological inputs but the loading is based on the projected 2017 conditions for the watershed (e.g., precipitation)

5. **Episodic release (2029):** This scenario simulates the extreme discharge conditions based on the September storm event in 2008. As in scenario 4, the wind and other meteorological conditions on the lake are based on the 2008 data but the watershed loading is based on the projected 2029 conditions for the watershed (e.g., precipitation).

3.4.1 Scenario 1: Baseline condition

Concentrations of water quality variables at major water intake locations are shown in Figures 23-32. The results are obtained using meteorological data from 2008 to force the hydrodynamic model. Observations at Burns Ditch, Indiana harbor Canal, and Calumet are used to provide input for the water quality model.

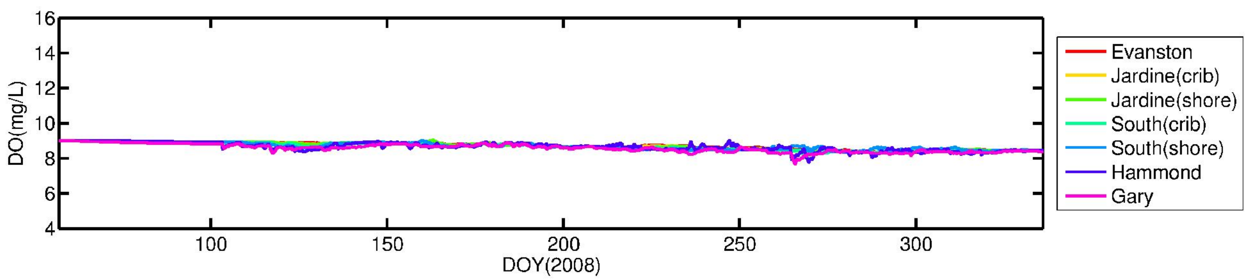

Figure 3.25 Concentration of DO at the major drinking water intake locations based on Scenario 1

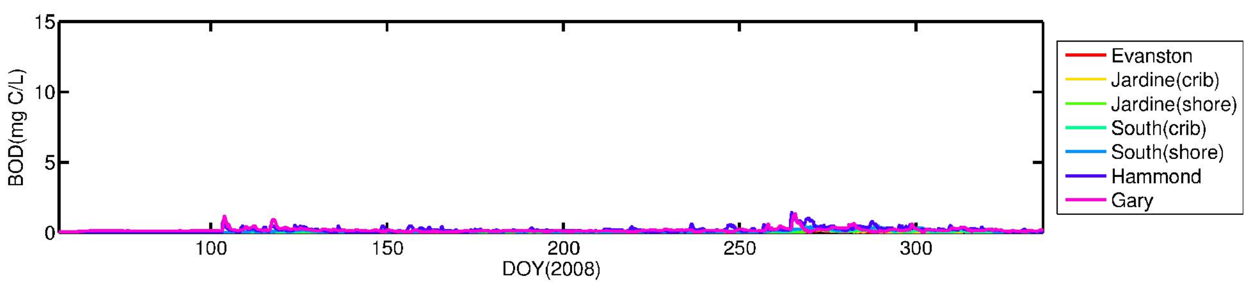

Figure 3.26 Concentration of BOD at the major drinking water intake locations based on Scenario 1

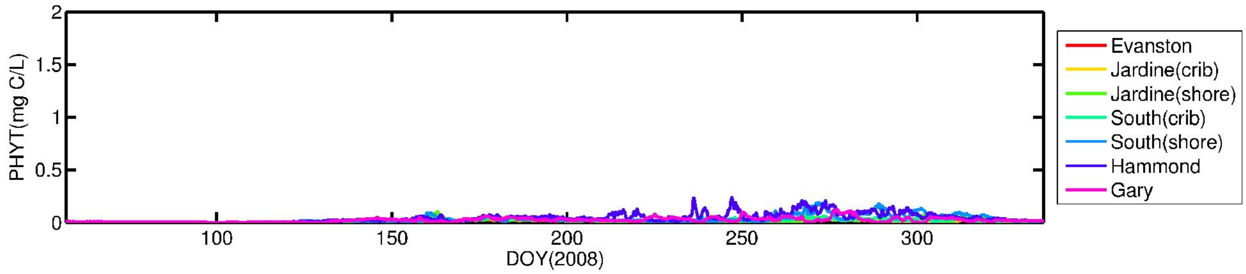

Figure 3.27 Concentration of phytoplankton at the major drinking water intake locations based on
Scenario 1

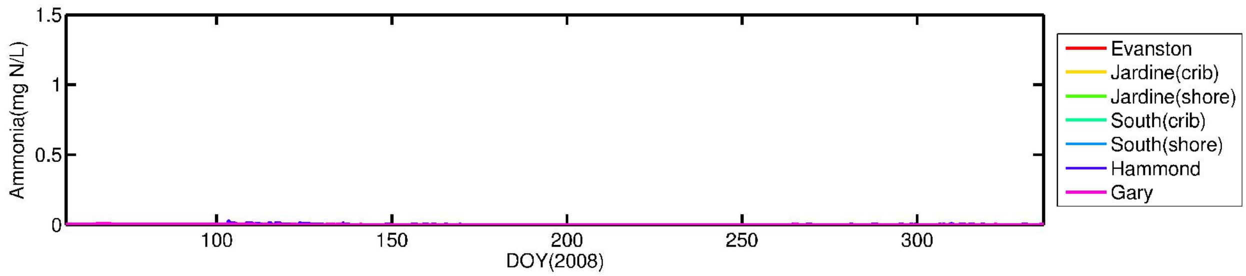

Figure 3.28 Concentration of ammonia at the major drinking water intake locations based on
Scenario 1

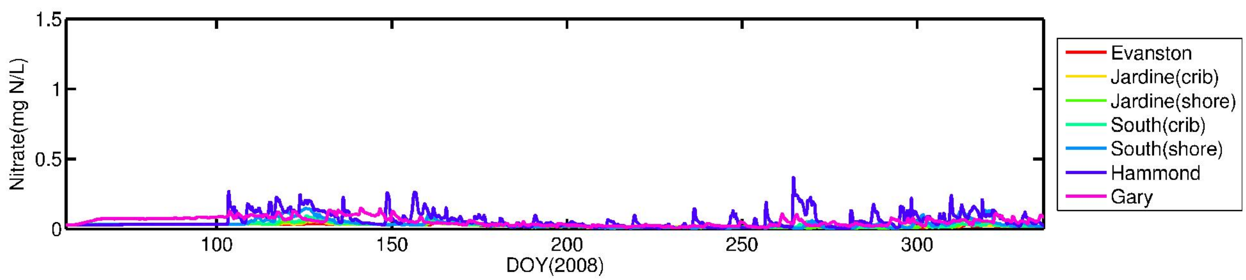

Figure 3.29 Concentration of nitrate at the major drinking water intake locations based on
Scenario 1

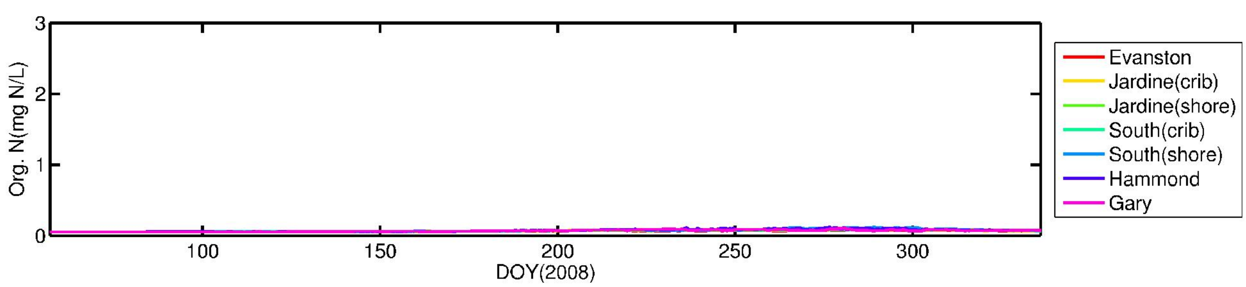

Figure 3.30 Concentration of organic nitrogen at the major drinking water intake locations based on
Scenario 1

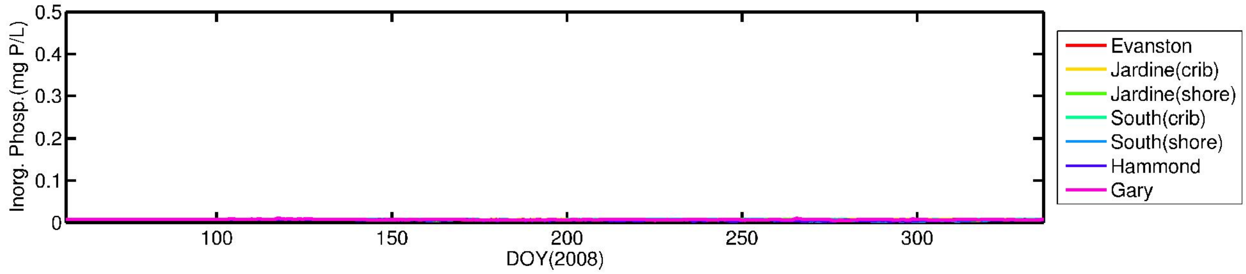

Figure 3.31 Concentration of ortho-phosphate at the major drinking water intake locations based on
Scenario 1

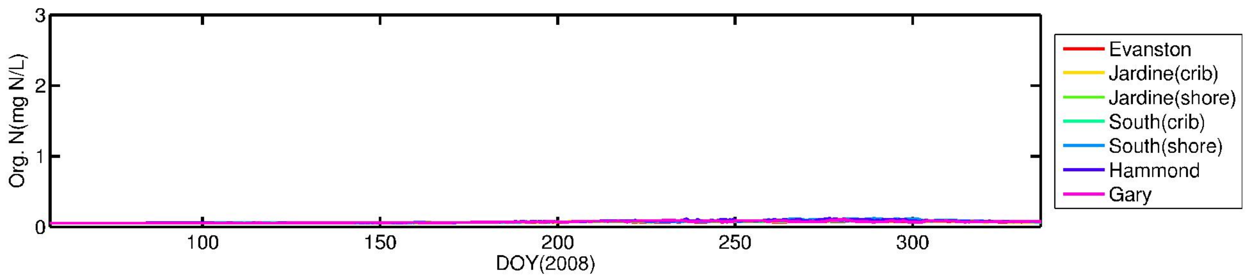

Figure 3.32 Concentration of organic phosphorous at the major drinking water intake locations based on
Scenario 1

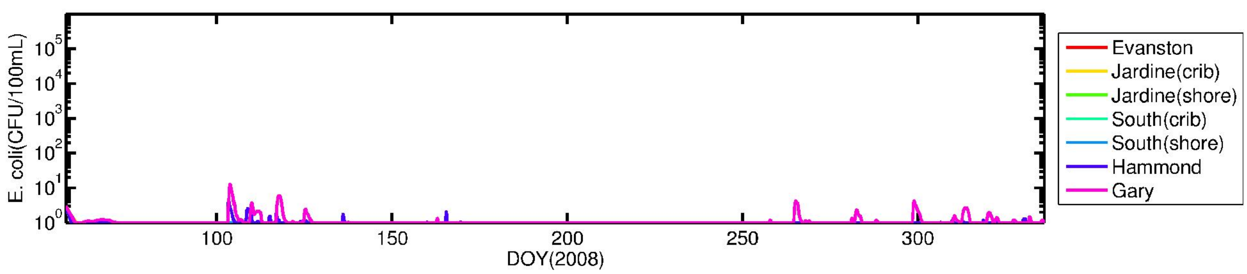

Figure 3.33 Concentration of FIB at the major drinking water intake locations based on
Scenario 1

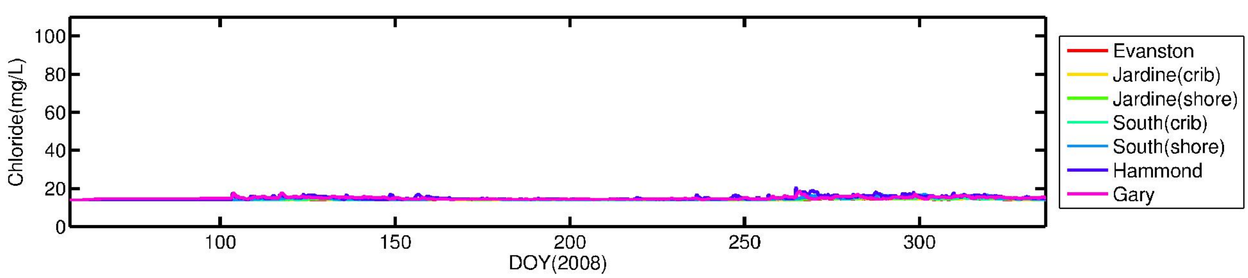

Figure 3.34 Concentration of chloride at the major drinking water intake locations based on
Scenario 1

3.4.2 Scenario 2: Continuous release (2017)

Concentrations of water quality variables at major water intake locations are shown in Figures 33-42. The results are obtained using meteorological data from water year 2008 (Sept 2007-October 2008) to force the hydrodynamic model. Watershed model results at Calumet, Indiana Harbor Canal, Calumet, Chicago, and Wilmette and observations from 2008 at Burns Ditch are used to provide input for the water quality model.

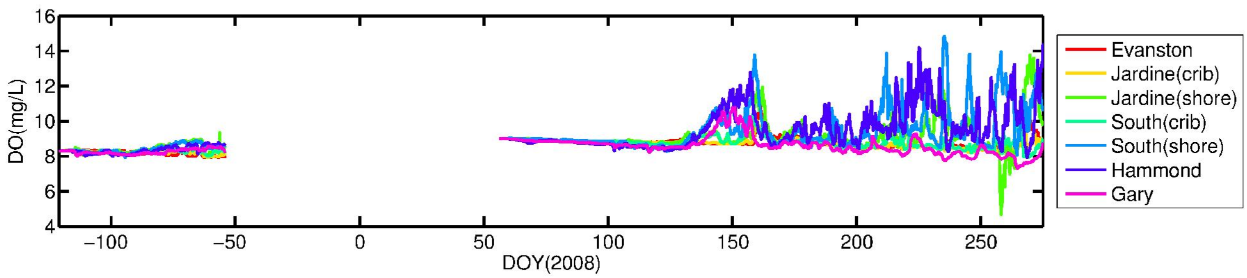

Figure 3.35 Concentration of DO at the major drinking water intake locations based on Scenario 1

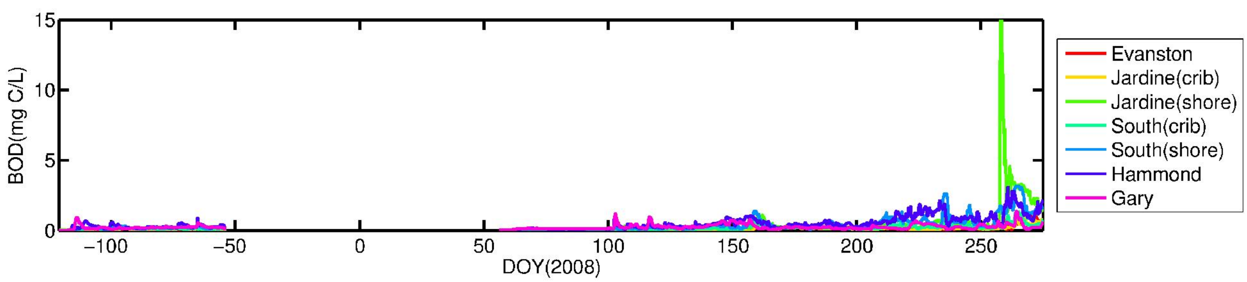

Figure 3.36 Concentration of BOD at the major drinking water intake locations

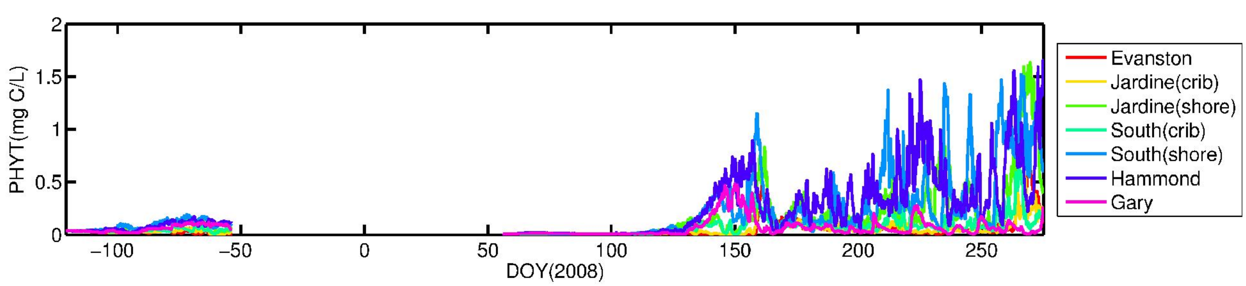

Figure 3.37 Concentration of Phytoplankton at the major drinking water intake locations

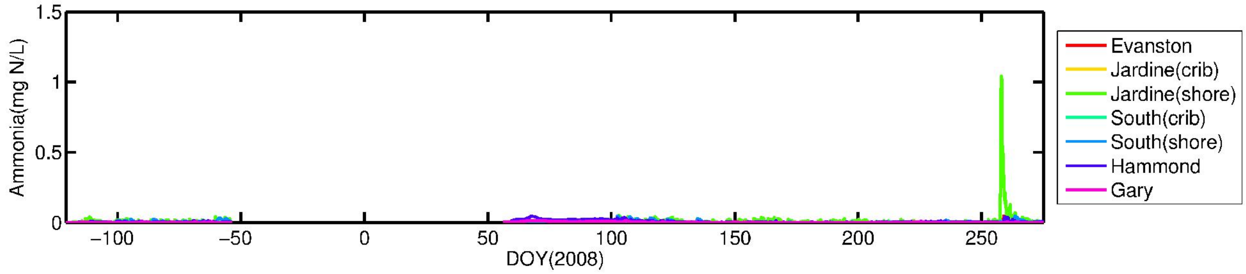

Figure 3.38 Concentration of Ammonia at the major drinking water intake locations

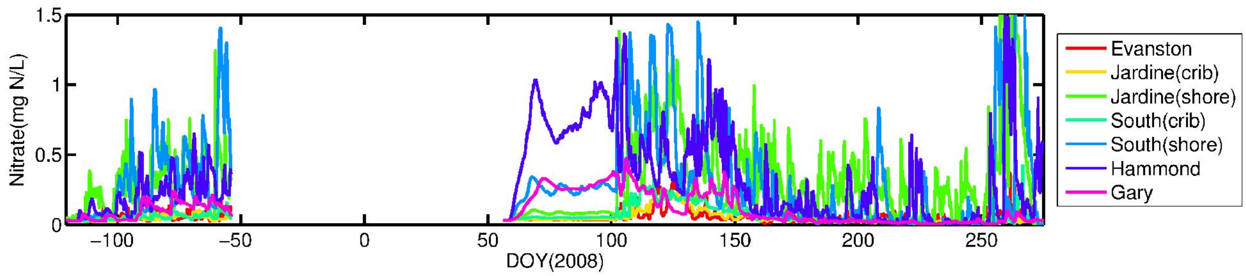

Figure 3.39 Concentration of Nitrate at the major drinking water intake locations

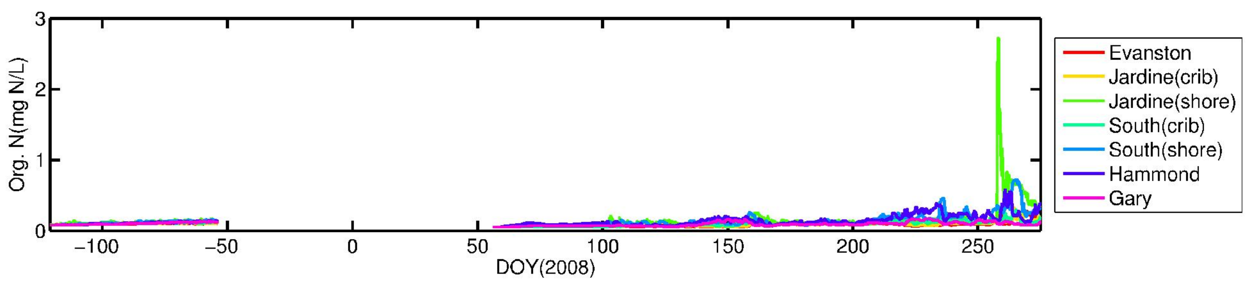

Figure 3.40 Concentration of Organic Nitrogen at the major drinking water intake locations

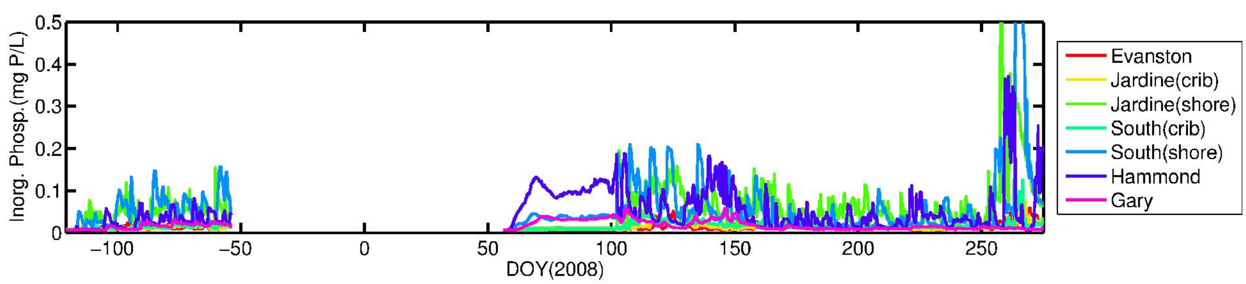

Figure 3.41 Concentration of ortho phosphate at the major drinking water intake locations

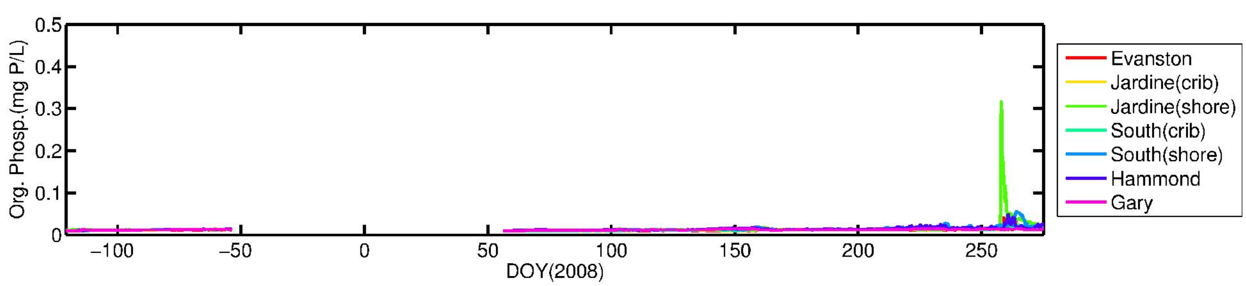

Figure 3.42 Concentration of Organic Phosphorous at the major drinking water intake locations

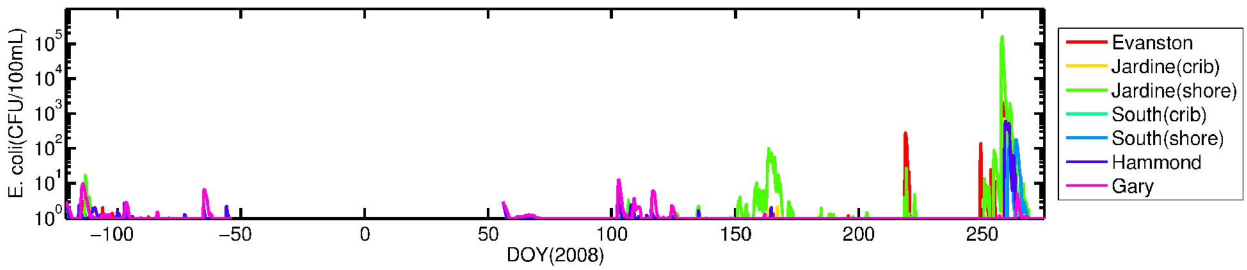

Figure 3.43 Concentration of FIB at the major drinking water intake locations

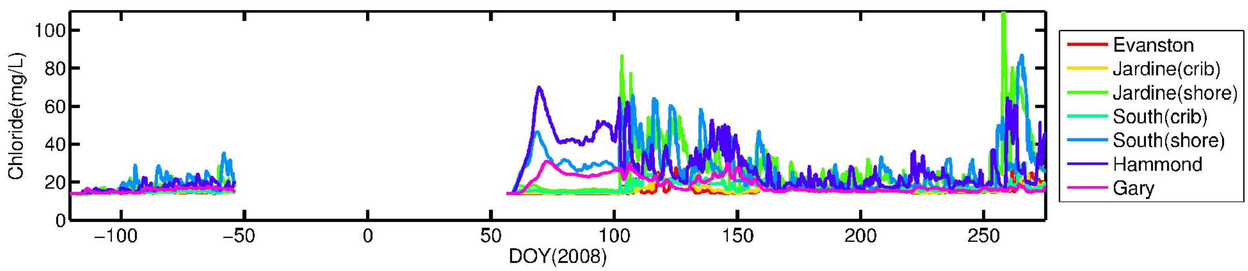

Figure 3.44 Concentration of Chloride at the major drinking water intake locations

3.4.3 Scenario 3: Continuous release (2029)

Concentrations of water quality variables at major water intake locations are shown in the Figures 43-52. The results are obtained using meteorological data from water year 2008 (Sept 2007- October 2008) to force the hydrodynamic model. Watershed model results at Calumet, Indiana Harbor Canal, Calumet, Chicago, and Wilmette and observations from 2008 at Burns Ditch are used to provide input for the water quality model.

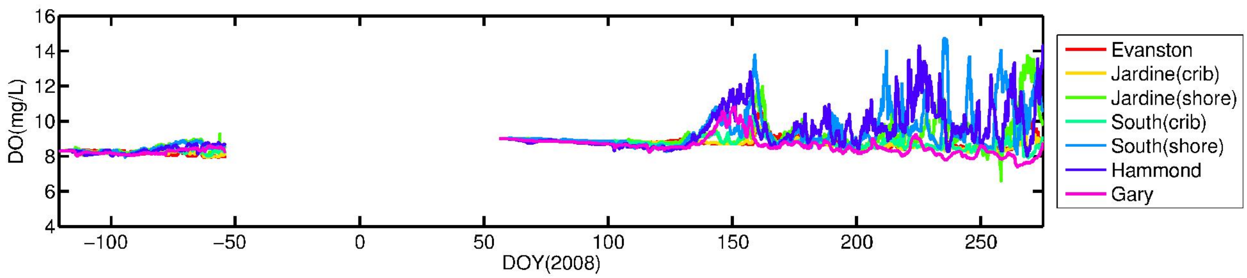

Figure 3.45 Concentration of DO at the major drinking water intake locations

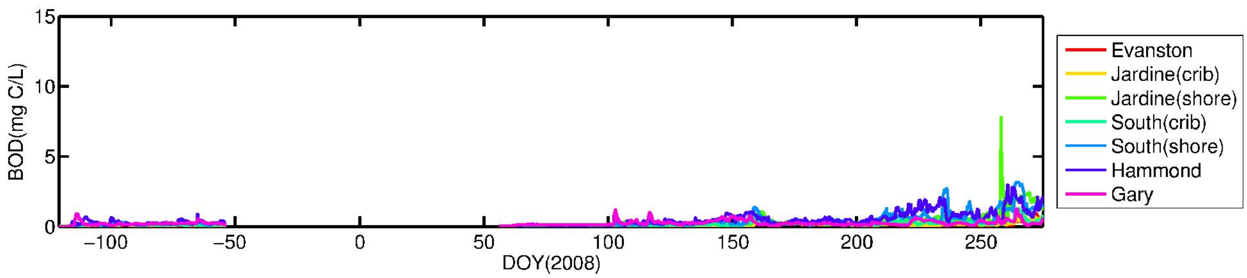

Figure 3.46 Concentration of BOD at the major drinking water intake locations

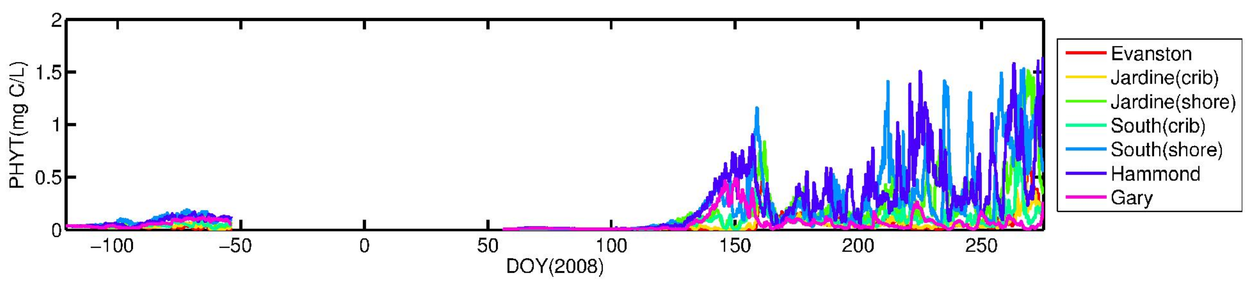

Figure 3.47 Concentration of Phytoplankton at the major drinking water intake locations

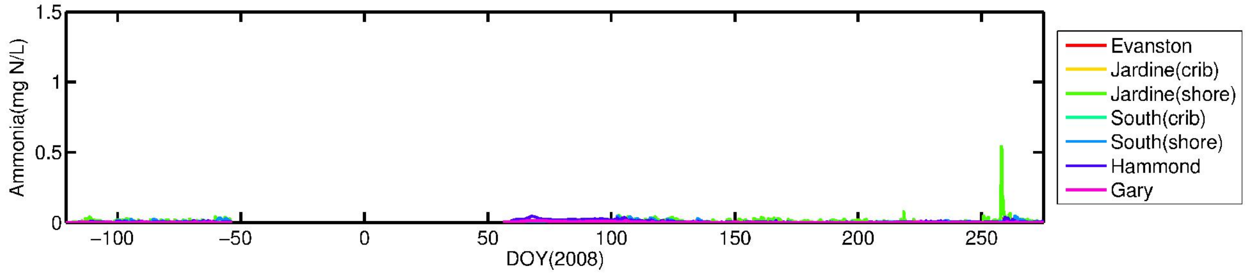

Figure 3.48 Concentration of Ammonia at the major drinking water intake locations

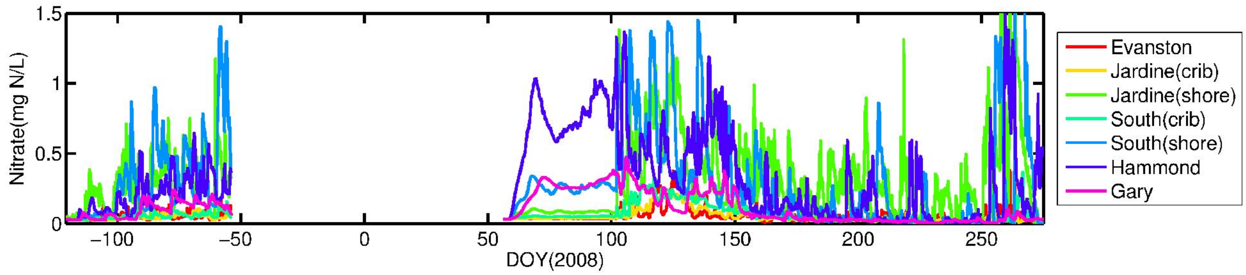

Figure 3.49 Concentration of Nitrate at the major drinking water intake locations

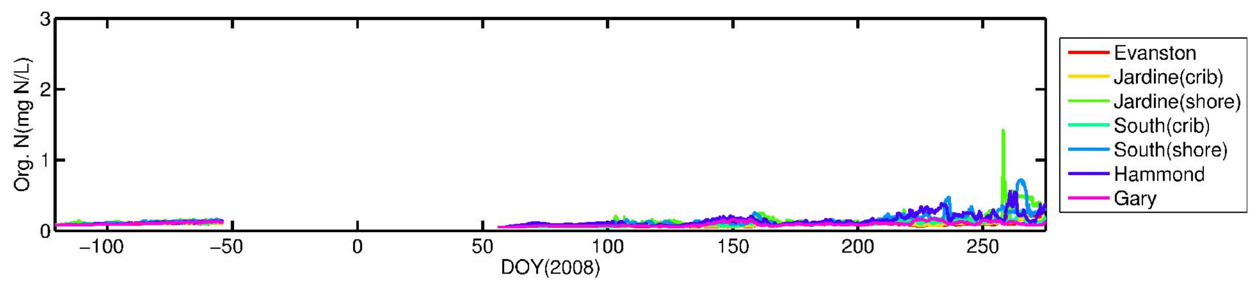

Figure 3.50 Concentration of Organic Nitrogen at the major drinking water intake locations

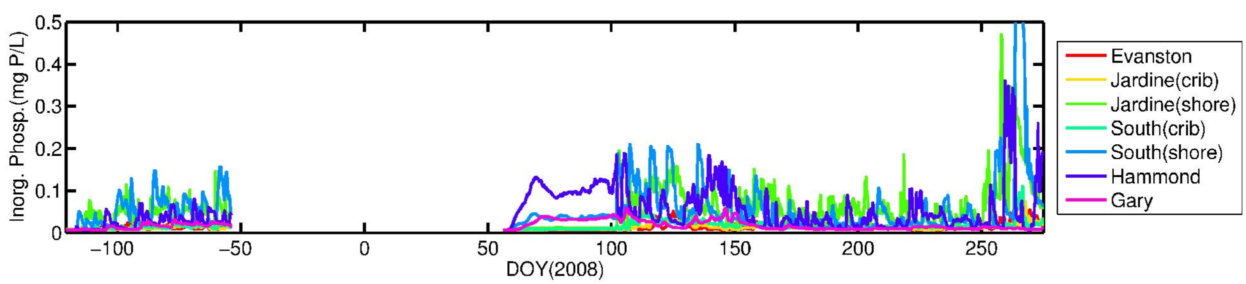

Figure 3.51 Concentration of ortho phosphate at the major drinking water intake locations

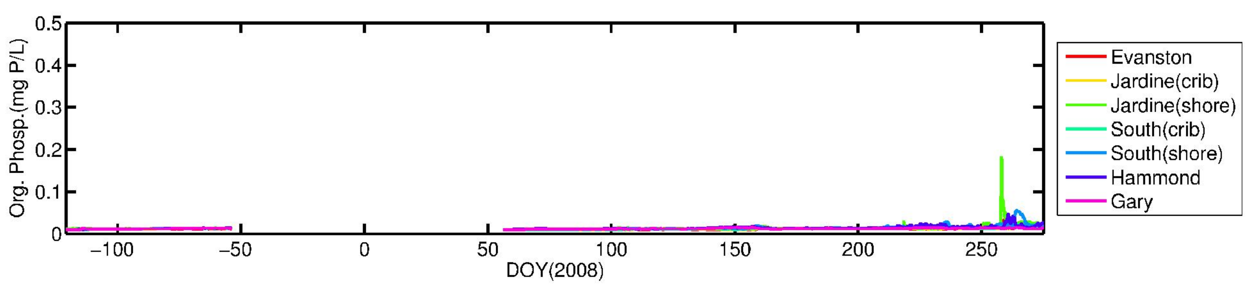

Figure 3.52 Concentration of organic phosphorous at the major drinking water intake locations

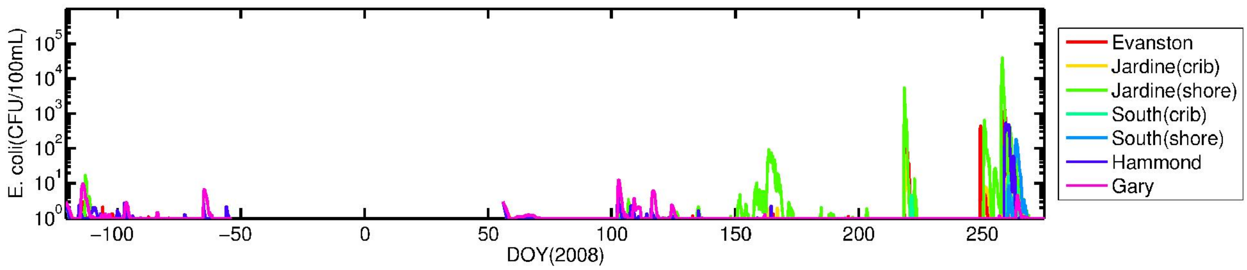

Figure 3.53 Concentration of FIB at the major drinking water intake locations

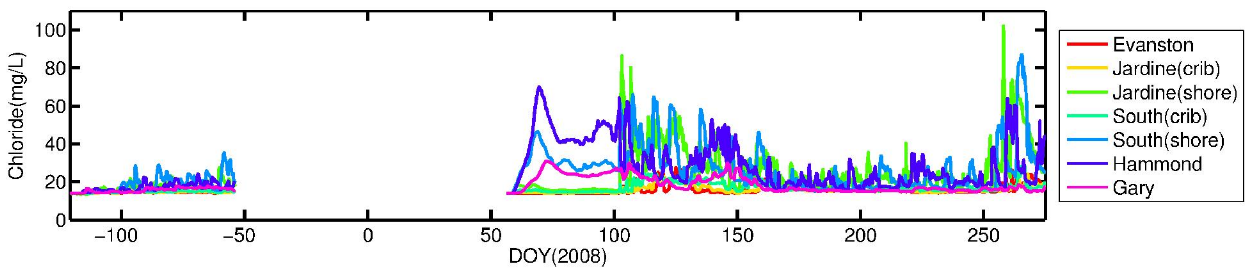

Figure 3.54 Concentration of Chloride at the major drinking water intake locations

3.4.5 Scenario 4: Episodic release (2017)

Concentrations of water quality variables at major water intake locations are shown in the Figures 53-62. The results are obtained using meteorological data from 2008 to force the hydrodynamic model. Watershed model results for the September storm event are used to provide input for the water quality model. The water quality and hydrodynamic models were run until plume (discharge) dissipation. The results for the period September 10 to October 10 are presented.

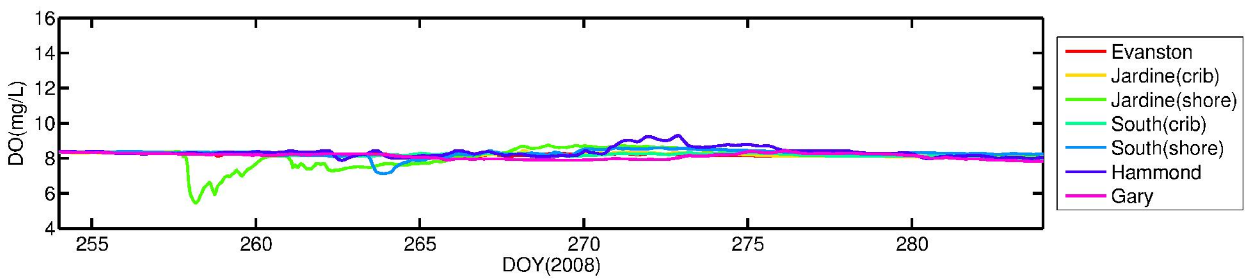

Figure 3.55 Concentration of DO at the major drinking water intake locations

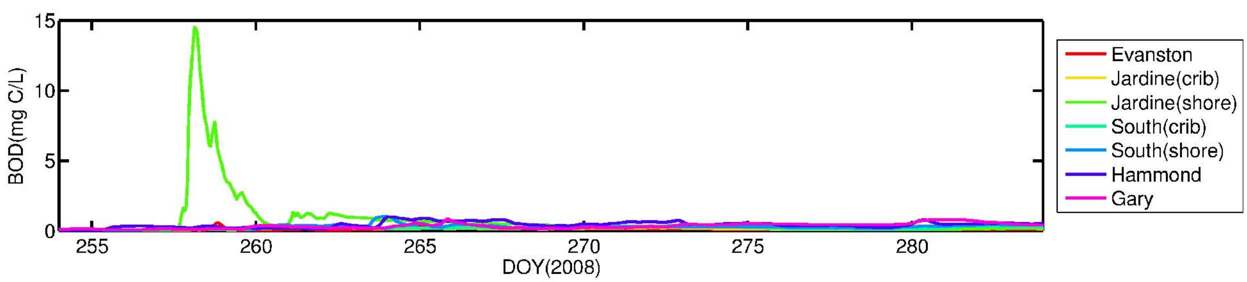

Figure 3.56 Concentration of BOD at the major drinking water intake locations

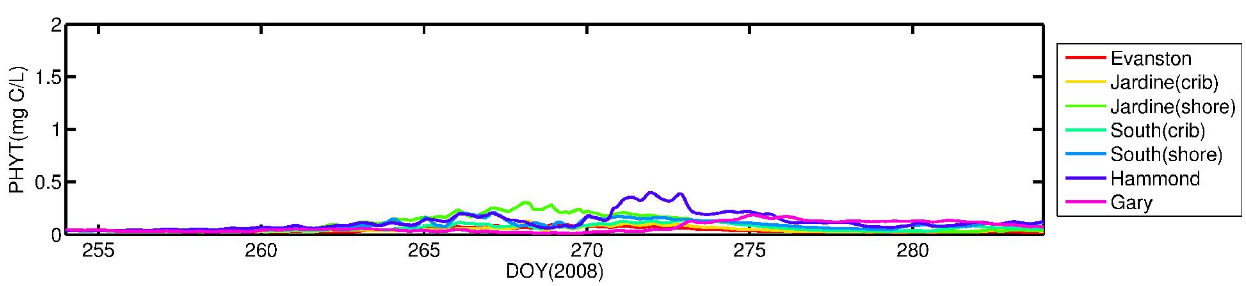

Figure 3.57 Concentration of phytoplankton at the major drinking water intake locations

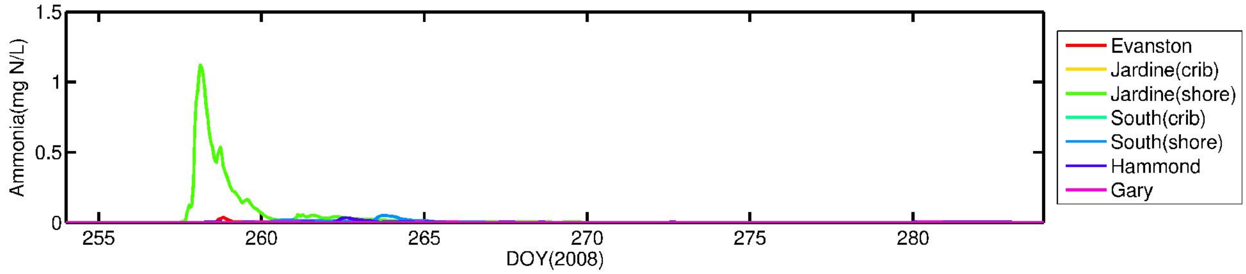

Figure 3.58 Concentration of ammonia at the major drinking water intake locations

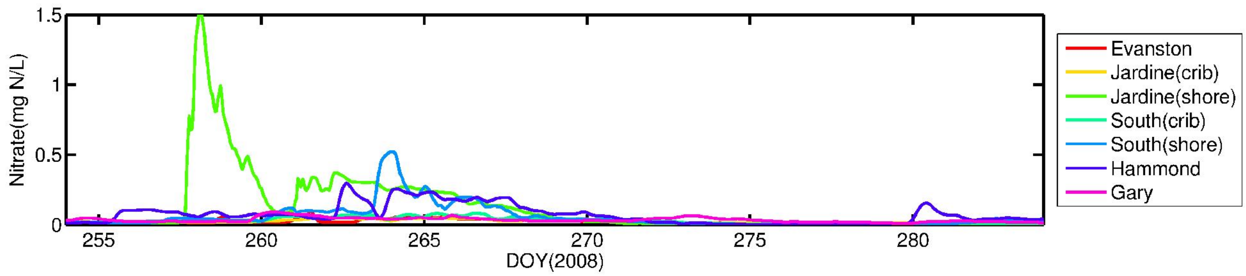

Figure 3.59 Concentration of nitrate at the major drinking water intake locations

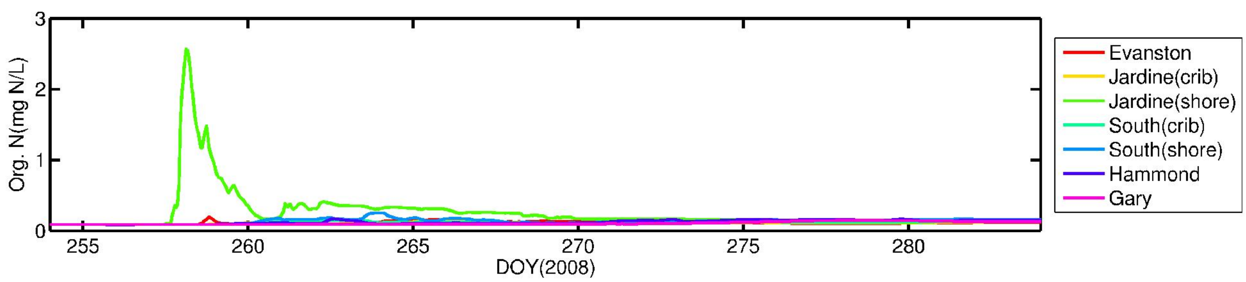

Figure 3.60 Concentration of organic nitrogen at the major drinking water intake locations

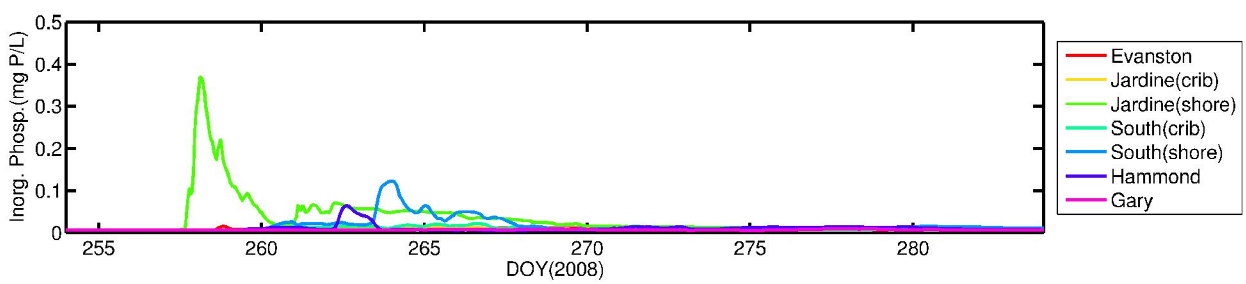

Figure 3.61 Concentration of inorganic phosphorous at the major drinking water intake locations

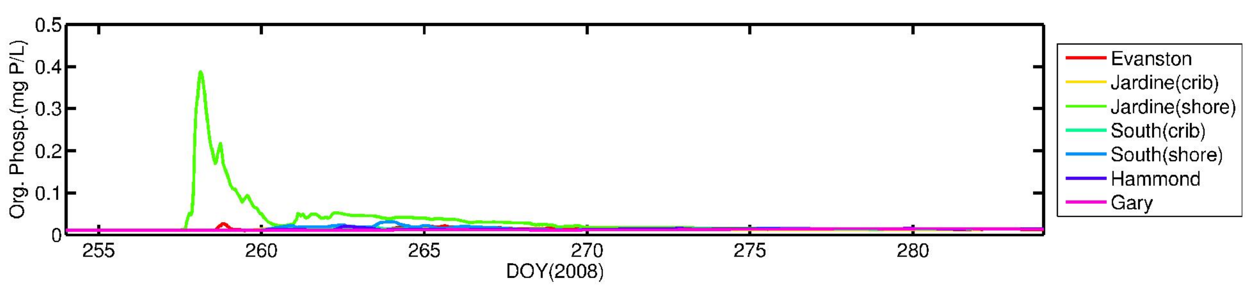

Figure 3.62 Concentration of organic phosphorous at the major drinking water intake locations

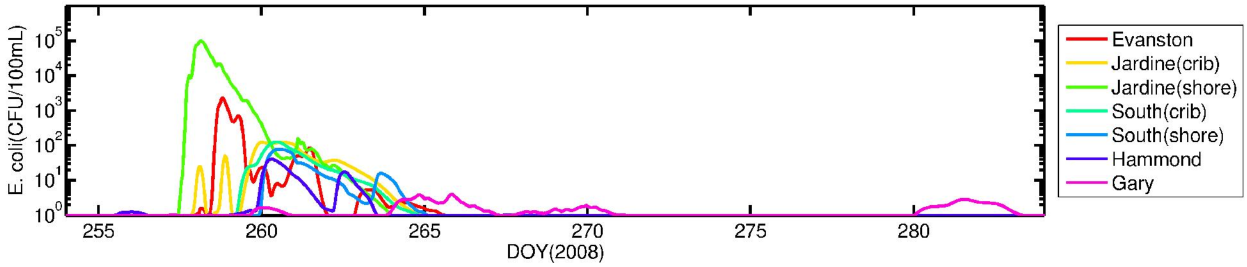

Figure 3.63 Concentration of FIB at the major drinking water intake locations

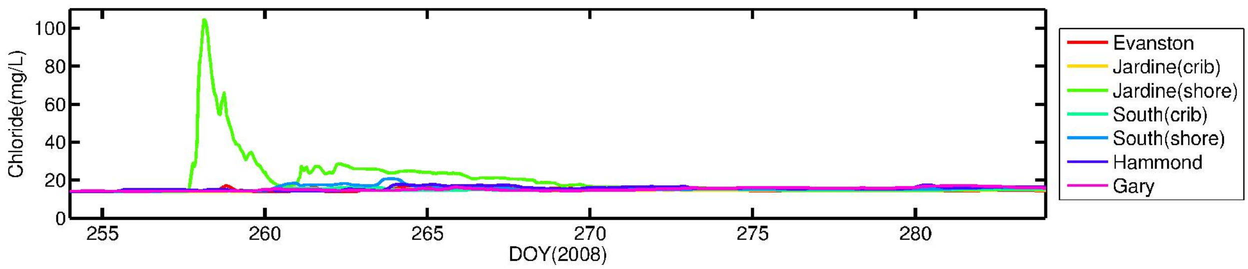

Figure 3.64 Concentration of chloride at the major drinking water intake locations

3.4.4 Scenario 5: Episodic release (2029)

Concentrations of water quality variables at major water intake locations are shown in the Figures 63-72. The results are obtained using meteorological data from 2008 to force the hydrodynamic model. Watershed model results for the September storm event are used to provide input for the water quality model. The water quality and hydrodynamic models were run until plume (discharge) dissipation. The results for the period September 10 to October 10 are presented.

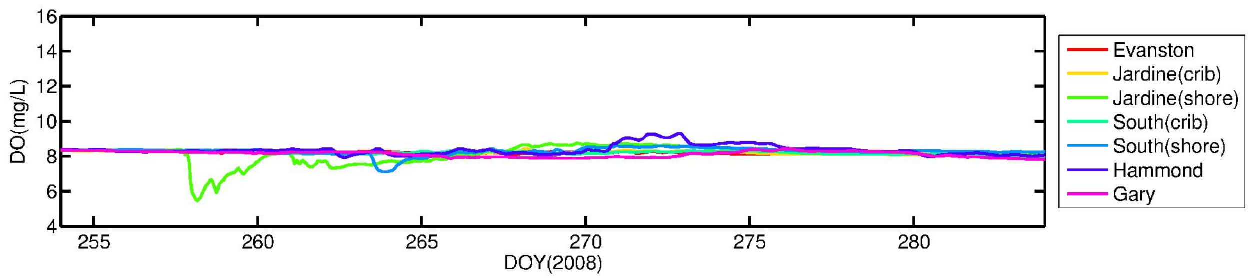

Figure 3.65 Concentration of DO at the major drinking water intake locations

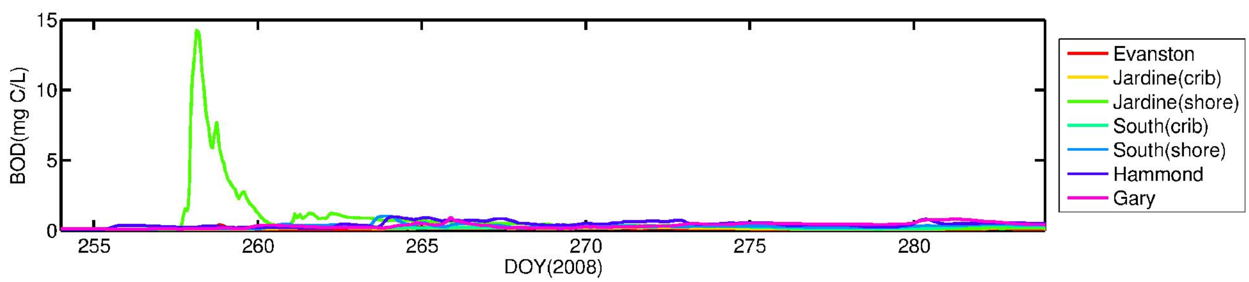

Figure 3.66 Concentration of BOD at the major drinking water intake locations

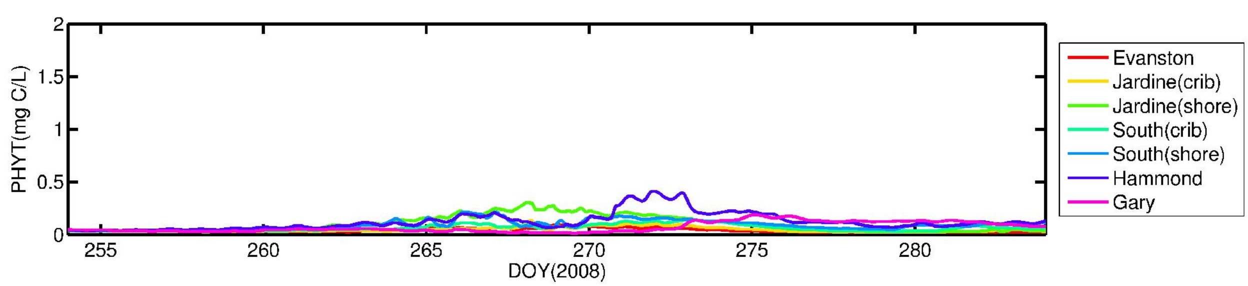

Figure 3.67 Concentration of phytoplankton at the major drinking water intake locations

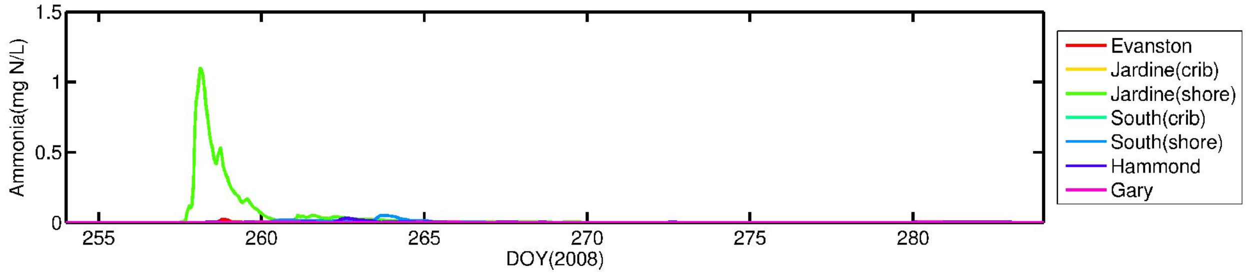

Figure 3.68 Concentration of Ammonia at the major drinking water intake locations

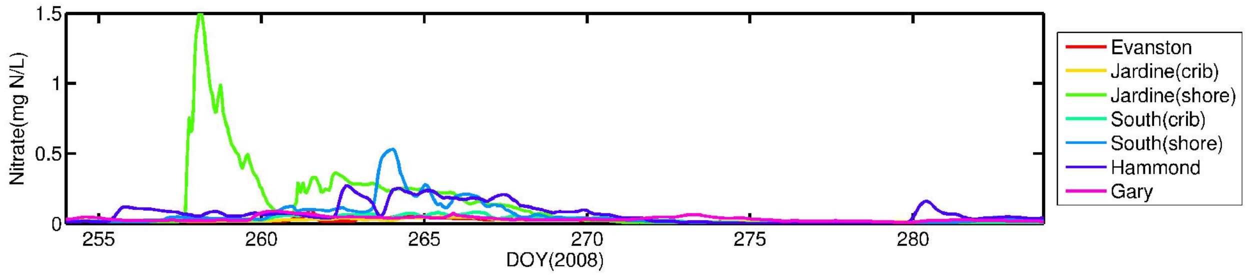

Figure 3.69 Concentration of Nitrate at the major drinking water intake locations

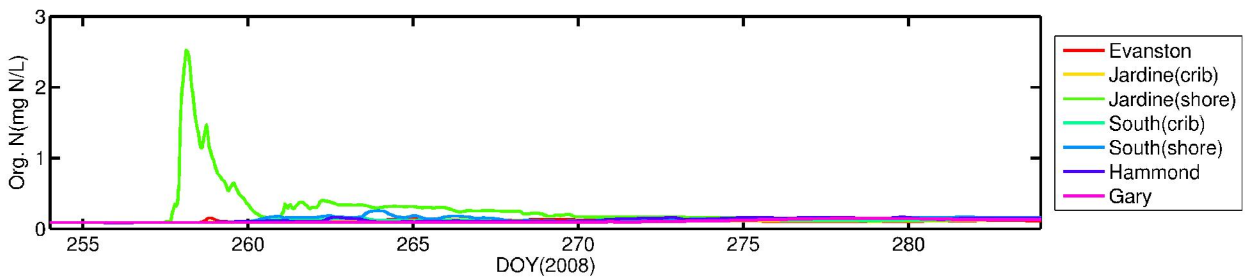

Figure 3.70 Concentration of organic nitrogen at the major drinking water intake locations

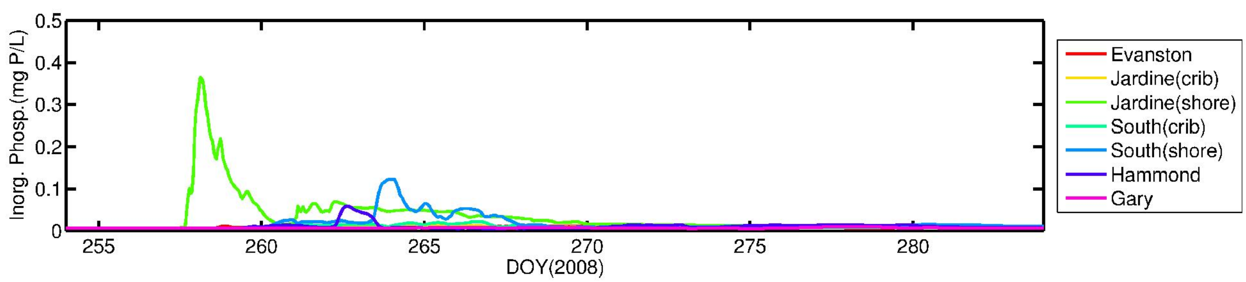

Figure 3.71 Concentration of ortho phosphate at the major drinking water intake locations

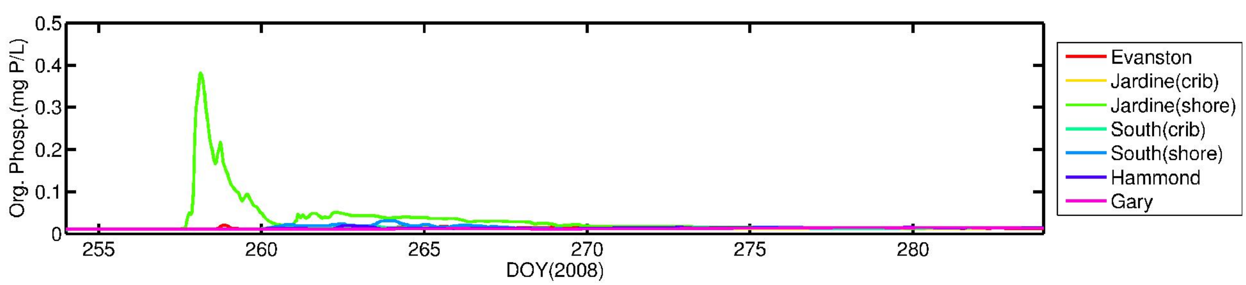

Figure 3.72 Concentration of organic phosphorous at the major drinking water intake locations

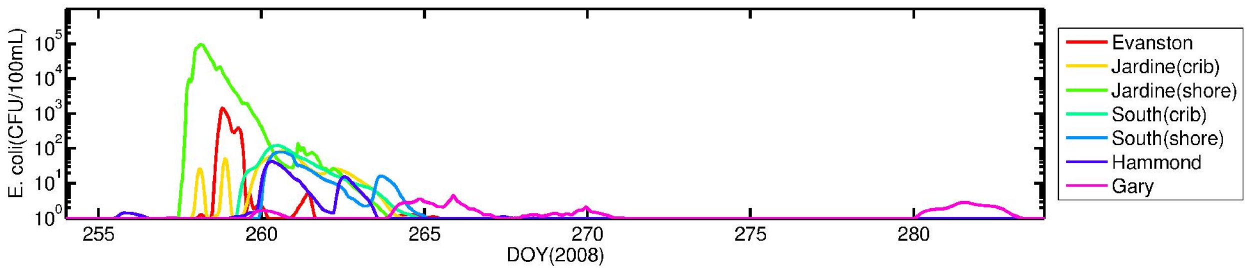

Figure 3.73 Concentration of FIB at the major drinking water intake locations

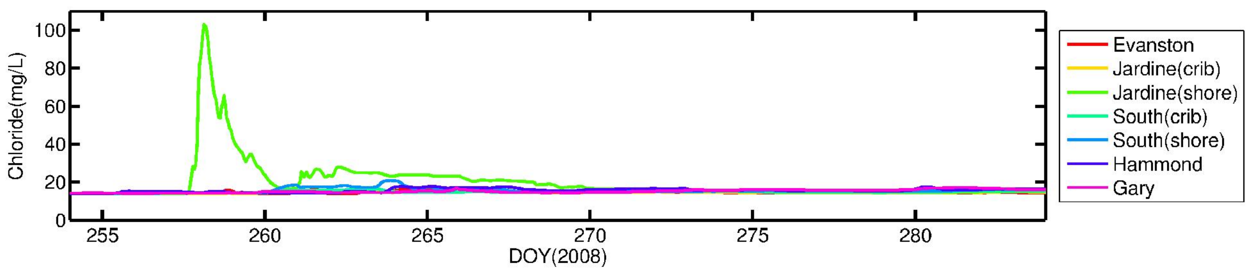

Figure 3.74 Concentration of chloride at the major drinking water intake locations

Chapter 4: Discussion

The hydrodynamic and water quality models were tested using data collected in 2008 and 2012. These data include current measurements at different locations in the nearshore region of Lake Michigan, concentrations of dissolved oxygen, biochemical oxygen demand, phytoplankton, nitrate, ammonia, *E. coli*, and chloride. The comparisons between the observed and simulated values of these water quality variables shown in Chapter 3 for the baseline conditions indicate that the model is able to simulate the mixing, transport, and the coupled physical-chemical-biological processes that affect the concentrations of water quality variables in the nearshore water column. However, a few of the peak values observed in the nearshore are not well predicted. It can also be seen that some of the variables (such as Chloride, *E. coli*, Phytoplankton, Nitrate, etc.) are better predicted by the model than other variables such as BOD, Ammonia etc.). This could be due to additional processes and/or sources that could potentially contribute to the contaminant levels in the nearshore environment. Further analysis of model sensitivity to the parameters and identifying the best (i.e., optimum) set of parameters to describe the processes in a large freshwater lake might also improve the comparisons. Identifying the optimum set of parameters in a multi-dimensional model with a large set of parameters is a computationally demanding task; therefore the parameter identification exercise in this study was limited due to lack of time.

For some scenarios (Scenario 2, Figure 3.33 in Chapter 3), the simulated dissolved oxygen levels are significantly higher than expected values. Closer examination revealed that these high DO values approaching 16 mg/L in concentration are due to surface algal blooms that occurred within the grid cell reporting the high DO value. Intense algal blooms produce high oxygen levels in the presence of sunlight due to photosynthesis and similar high DO concentrations have been measured in lakes in the past (see for example, *Batchelder and Braden*, 1976.)

As shown by the results from the different water quality model scenarios that were simulated, concentrations at different loading / discharge points have a significant impact on the nearshore water quality. The impact is more significant at locations closer to the shoreline as shown by the time-series of concentrations at the different intake locations shown in Chapter 3 (Figures 3.23 to 3.72). We find that mixing and diffusion processes quickly reduce pollutant concentrations to acceptable levels. The different candidate benchmarks for water quality in Lake Michigan (open waters) are given in Table 4.2.

Table 4.1.Candidate benchmarks for Lake Michigan open waters. Model statistics are calculated for Scenario 3 (simulating Sept 2008 storm with hydrologic separation barrier) at location Jardine (shore). Statistics are available for all locations in the Appendix.

Variable	Benchmark	Min.	Max.	Mean	Std. dev.	Days exceeded
Total Phosphorous	0.007 mg/L	0.024	0.651	0.153	0.103	30 out of 30
Ammonia	NA	0.0008	0.540	0.0211	0.055	NA
Chloride	12 mg/L	15.26	102.22	36.66	17.218	30 out of 30
DO	7.2 mg/L	6.60	13.71	9.986	1.787	0 out of 30
Nitrate	10 mg/L	0.0002	2.421	0.4984	0.491	0 out of 30
Fecal Coliform/ *E. coli*	20 CFU/100mL	1	38792	630.46	3577.3	11 out of 30
CBOD	NA	0.132	7.781	1.35	1.007	
Phytoplankton	NA	0.060	1.513	0.595	0.453	

Table 4.2.Candidate benchmarks for Lake Michigan open waters. Model statistics are calculated for Scenario 5 (simulating the September 2008 storm without hydrologic separation barrier) at location Jardine (shore). Statistics are available for all locations in the Appendix.

Variable	Benchmark	Min.	Max.	Mean	Std. dev.	Days exceeded
Total Phosphorous	0.007 mg/L	0012	0.74	0.060	0.093	30 out of 30
Ammonia	NA	0	1.09	0.034	0.130	NA
Chloride	12 mg/L	13.8	102.98	19.668	11.486	30 out of 30
DO	7.2 mg/L	5.47	8.74	8.155	0.543	1 out of 30
Nitrate	10 mg/L	0.003	1.52	0.127	0.224	0 out of 30
Fecal Coliform/ *E. coli*	20 CFU/100mL	1	95799	1728.8	9847.3	6 out of 30
CBOD	NA	0.002	14.23	0.696	1.738	NA
Phytoplankton	NA	0.022	0.307	0.096	0.074	NA

As shown by the results presented in Chapter 3 as well as in Table 4.1 and Table 4.2, the candidate benchmarks for only some of the water quality variables are exceeded at the major water intake locations even during major storm events (such as the 2008 September storm event simulated in scenarios 4 and 5). Tables 4.1 and 4.2 also show the minimum, maximum and standard deviations in the different variables of interest for monitoring water quality at intakes. These show that *E. coli*, Phosphorous exceed the benchmark values at nearshore intakes that are located close to major discharges into Lake Michigan.

4.1 Comparison between Scenario 3 and Scenario 5

The results from Scenario 3 (with hydrologic separation) and Scenario 5 (without hydrologic separation barrier) are presented in Table 4.1 and Table 4.2 respectively. The statistics and exceedance rates are calculated for a period of 30 days (Sept 1 - Sept 30) which covers the September storm event in 2008. The results suggest that in the presence of the hydrologic barrier during the storm event, the mean total phosphorous concentration is more than twice as high, but the maximum concentrations are comparable. The phytoplankton concentration is also similarly much higher in the presence of a hydrologic separation barrier due to a higher nutrient (inorganic phosphorous) availability in the water column. Other water quality variables of interest based on the benchmarks available to this study suggest similar values.

The number of days the benchmark is exceeded was also calculated for the same 30 day period (Sept 1 - Sept 30). An exceedance was reported if the prescribed water quality benchmark was exceeded at least 6 hours out of a 24 hour period. As shown by the results presented in Table 4.2, in the presence of the separation barrier, the number of exceedance of fecal indicator bacteria shows a significantly higher exceedance rate.

4.2 Vertical variability in concentrations

Concentrations of water quality variables show a lot of vertical variability in the water column. This is due to variations in temperature, sunlight intensity and the effect of sediment layer on biological and physical processes that affect process rates included in the water quality model. In order to graphically present the variability of different water quality variables within the water column, Figures 4.1-4.10 below show the concentrations at 5 ft. interval depths for September 2008 (scenario 3) model simulation. Except for the phytoplankton that shows higher growth rate at the surface and as a result shows a higher concentration at surface, most other water quality variables have a lower concentration at the surface and higher concentration at the bottom layers. In Figures 4.1-4.20, depths are shown in feet below the Chicago City Datum (CCD). The continuous release in Scenario 3 represents what would happen if hydrologic separation barriers were built on the Chicago Sanitary and Ship Canal and Cal-Sag Channel.

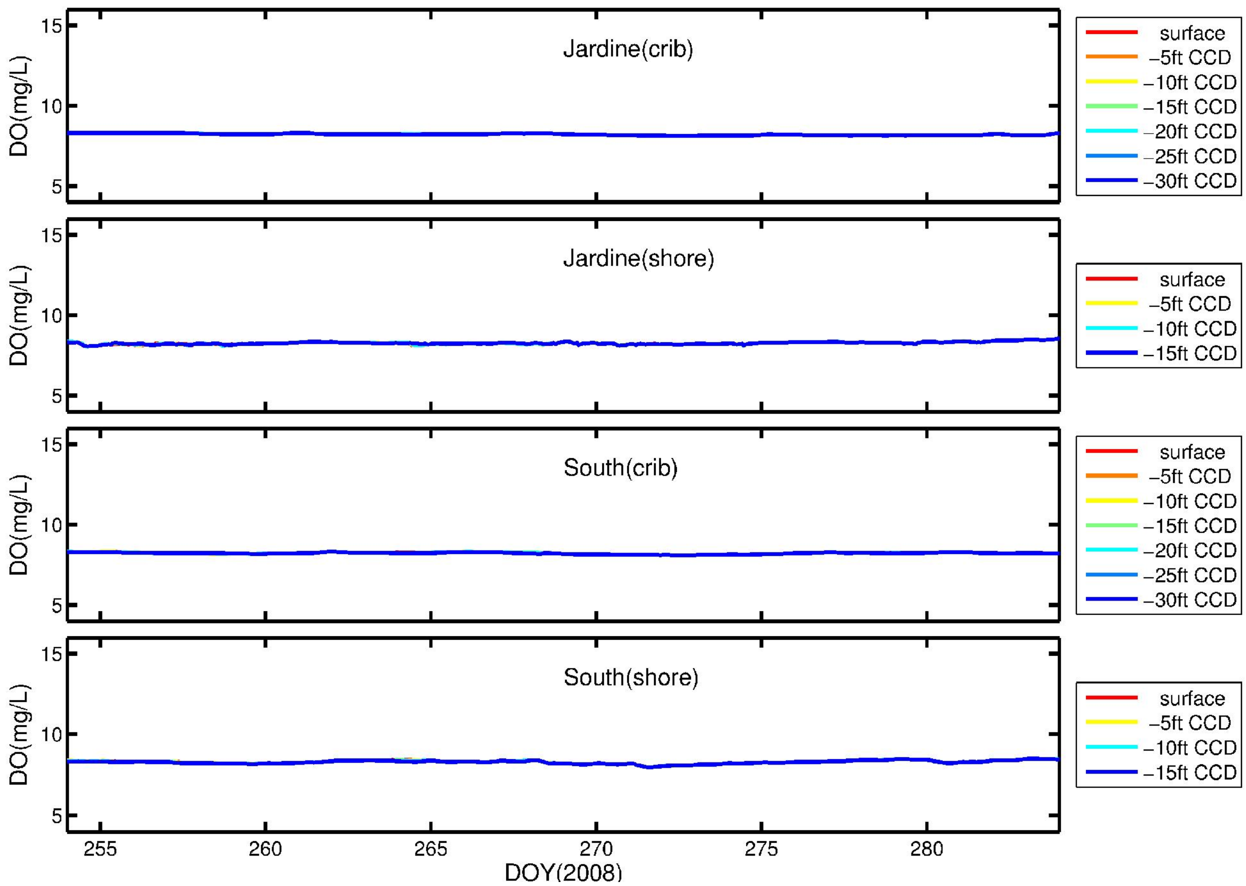

Figure 4.1 Concentration of dissolved oxygen at different depths at a few locations

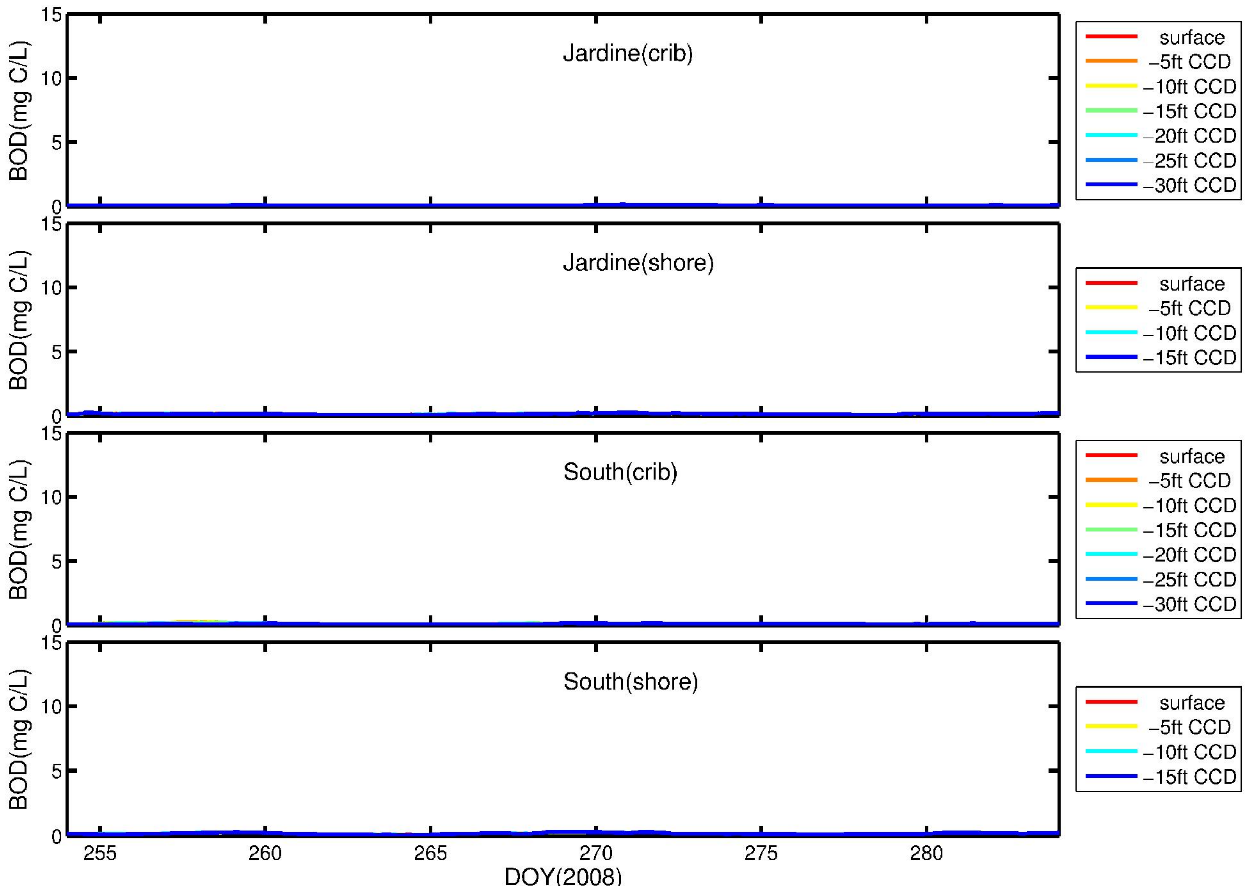

Figure 4.2 Concentration of oxygen demand at different depths at a few locations

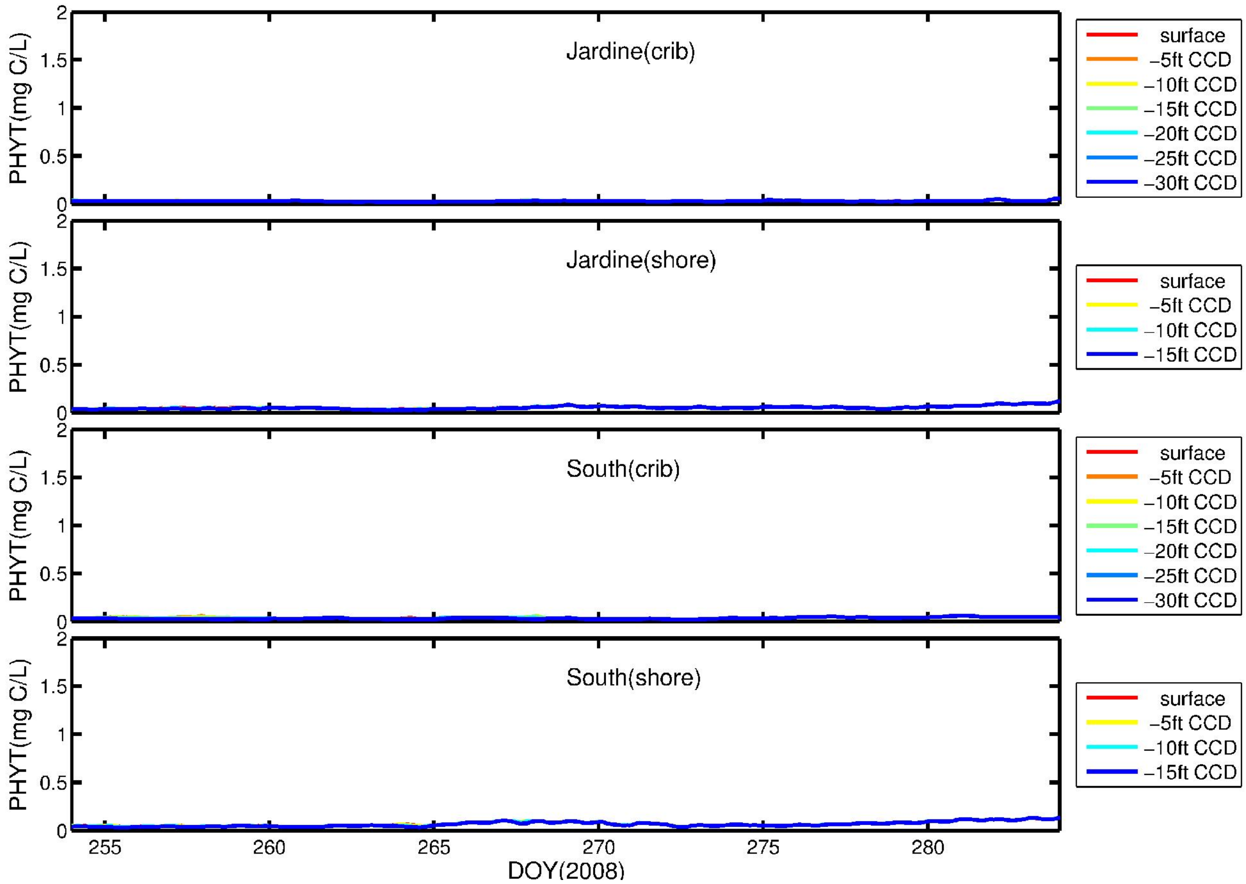

Figure 4.3 Concentration of phytoplankton at different depths at a few locations

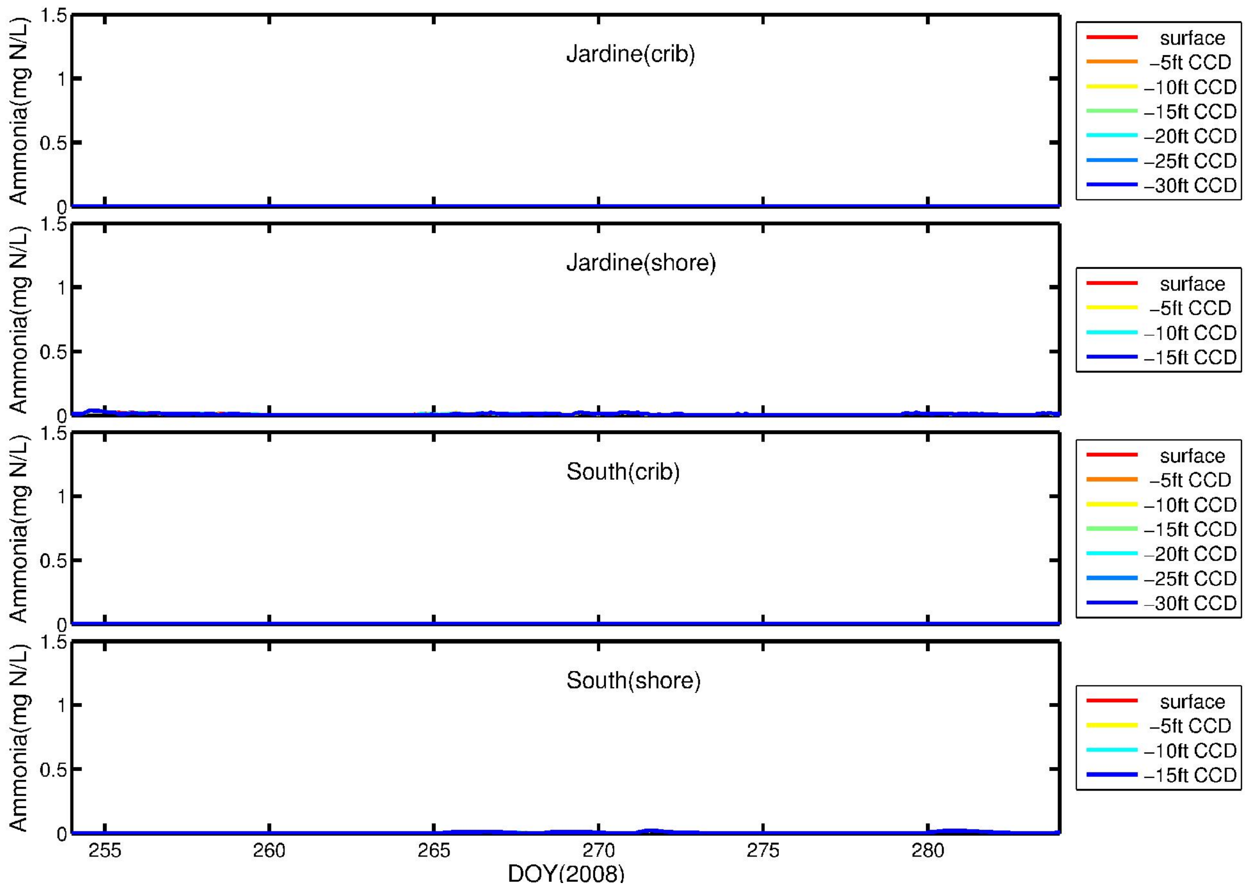

Figure 4.4 Concentration of ammonia at different depths at a few locations

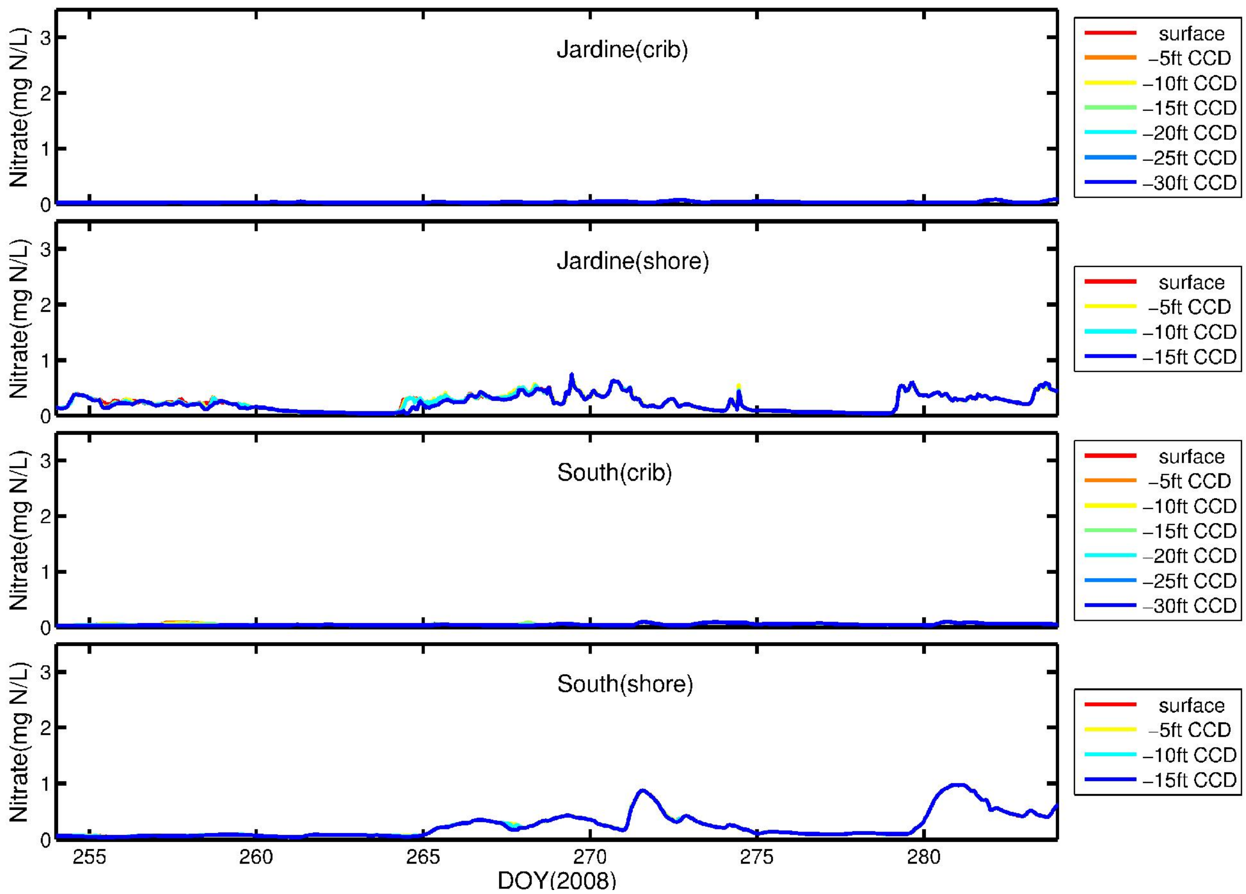

Figure 4.5 Concentration of nitrate at different depths at a few locations

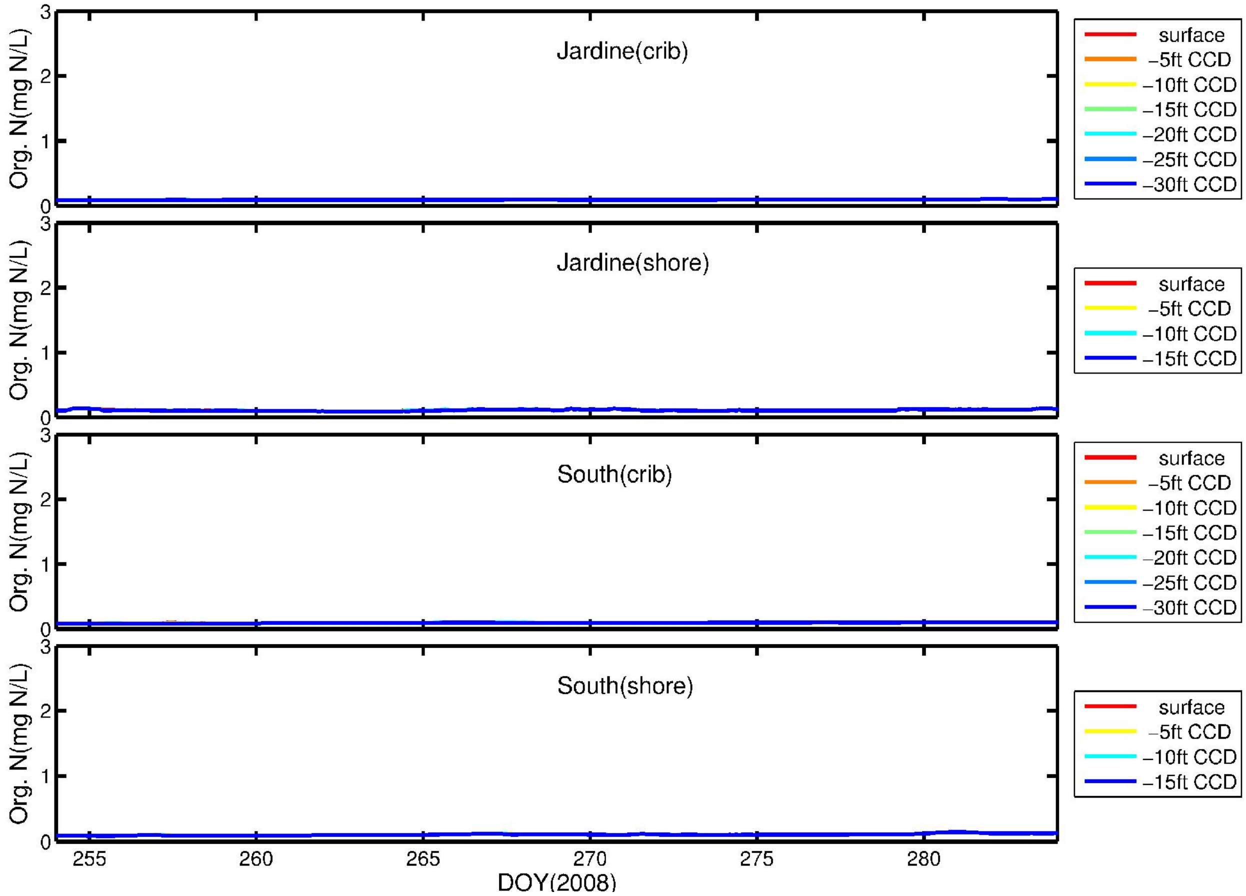

Figure 4.6 Concentration of organic nitrogen at different depths at a few locations

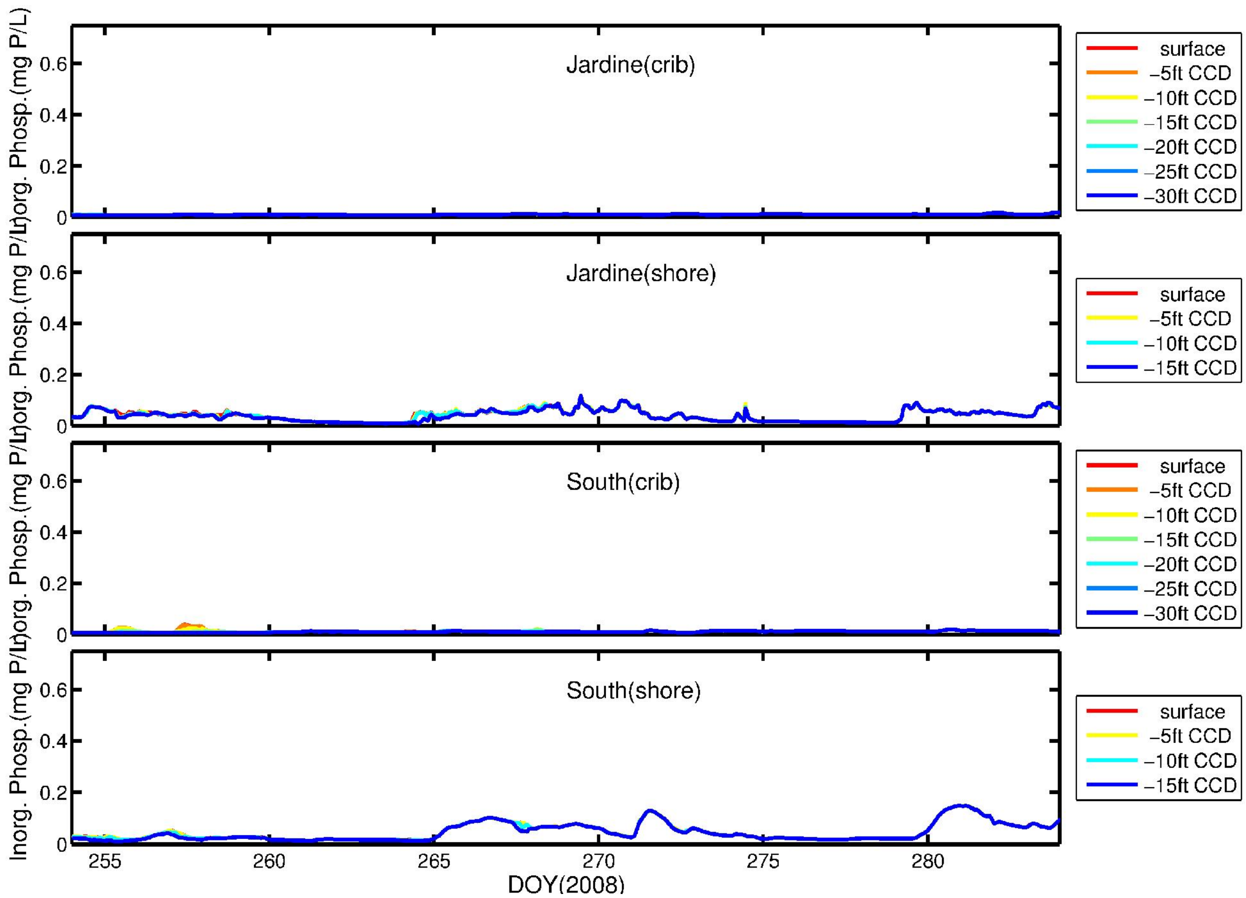

Figure 4.7 Concentration of ortho-phosphate at different depths at a few locations

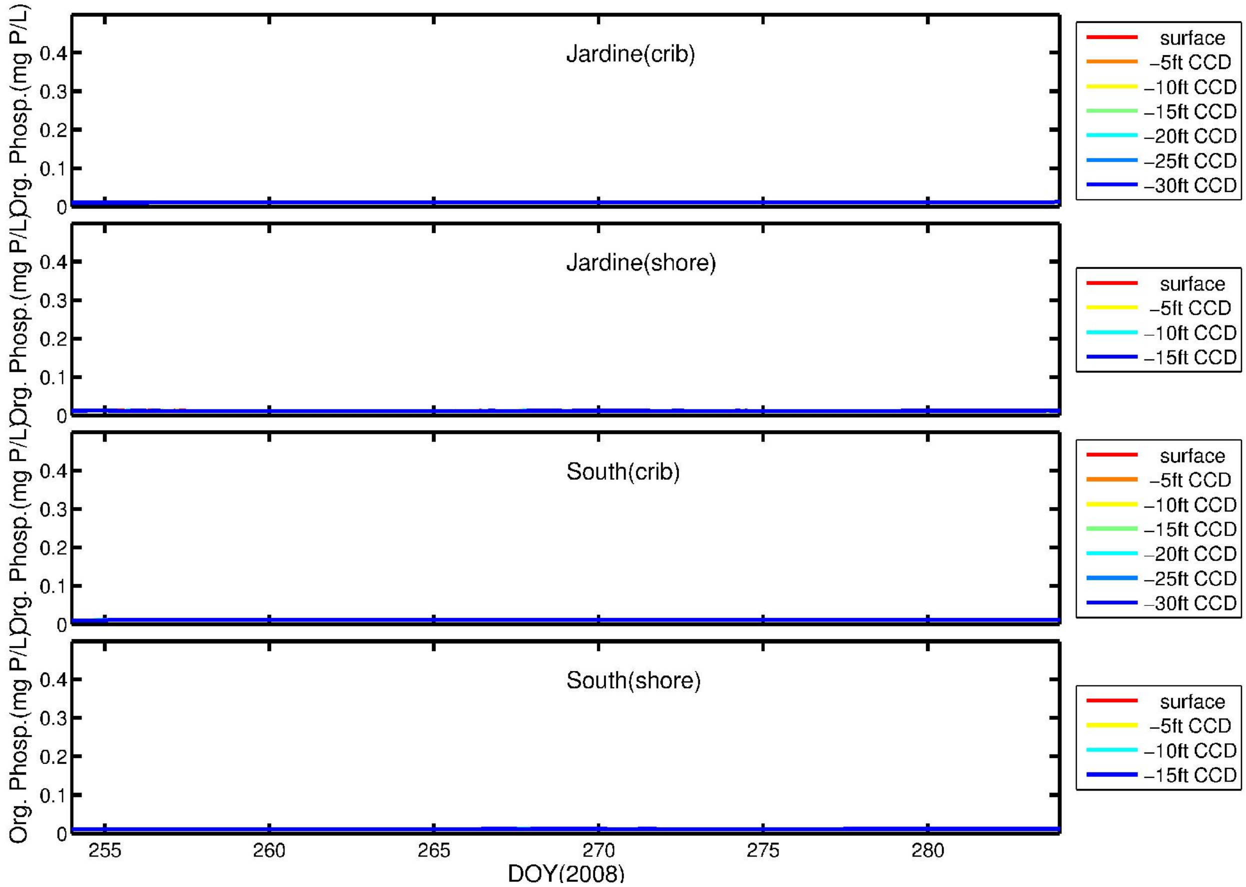

Figure 4.8 Concentration of organic phosphorous at different depths at a few locations

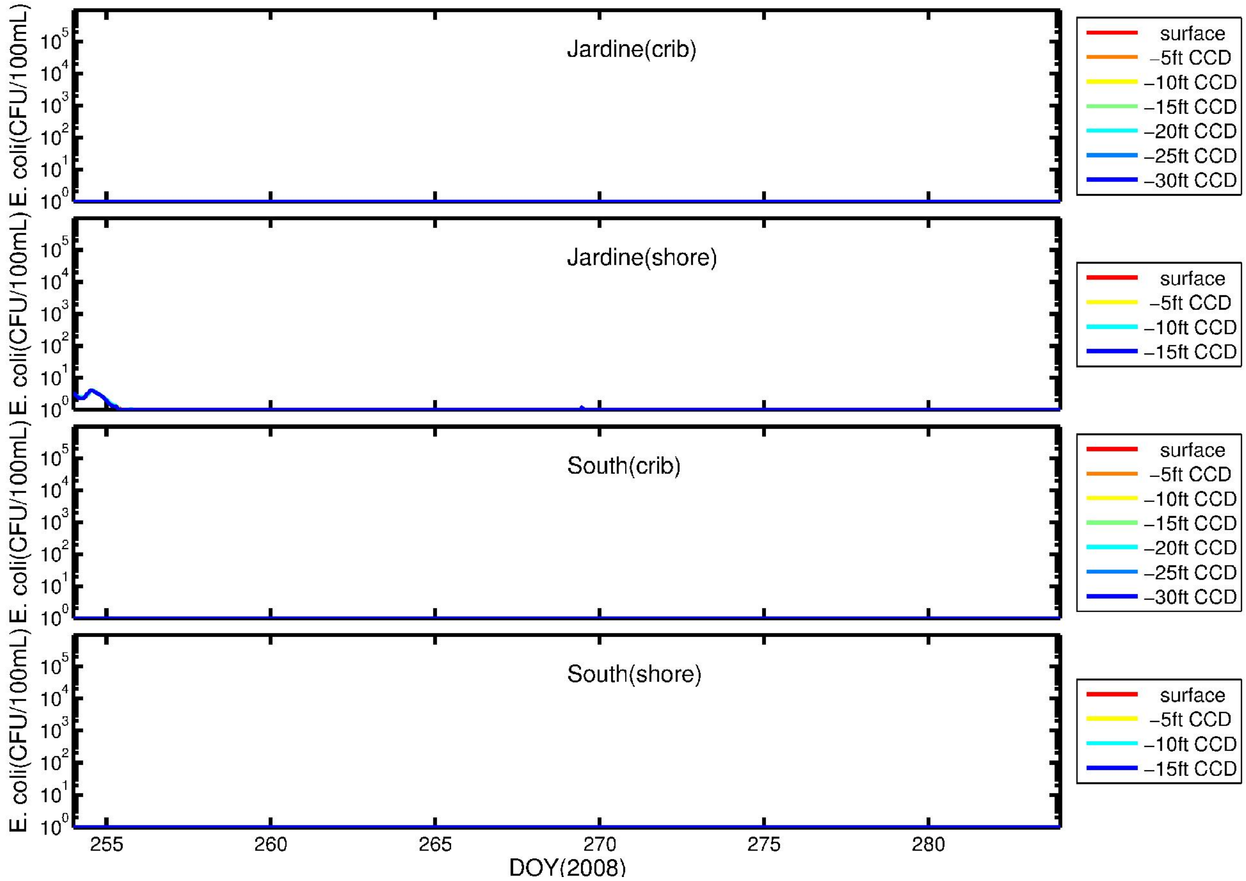

Figure 4.9 Concentration of *E. coli* at different depths at a few locations

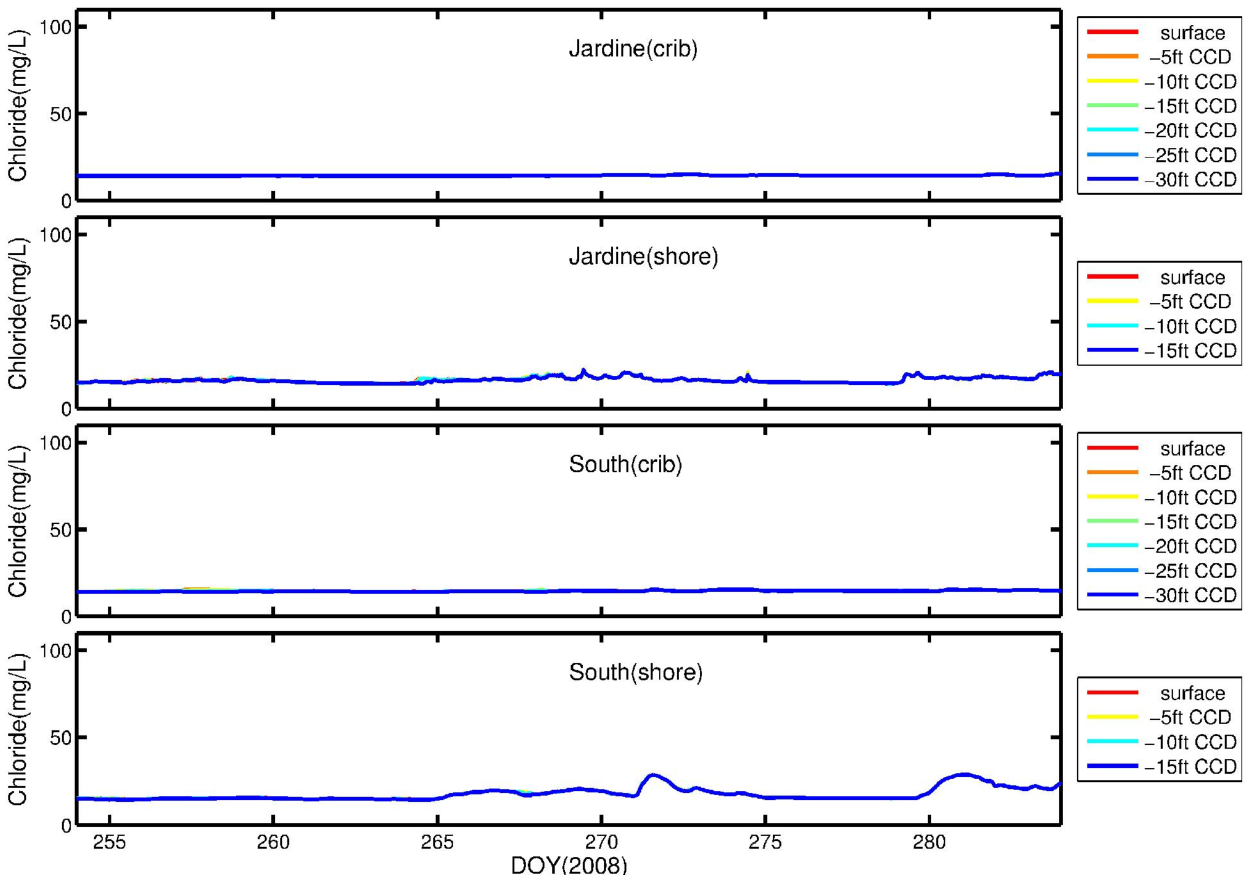

Figure 4.10 Concentration of chloride at different depths at a few locations

Figures 4.11-4.20 below show the concentrations at 5 ft. interval depths for September 2008 (scenario 5) model simulation. Except for the phytoplankton that shows higher growth rate at the surface and as a result shows a higher concentration at surface, most other water quality variables have a lower concentration at the surface and higher concentration at the bottom layers. In Figures 4.11-4.20, depths are shown in feet below the Chicago City Datum (CCD). The episodic release in Scenario 3 represents what would happen if hydrologic separation barriers were not built on the Chicago Sanitary and Ship Canal and Cal-Sag Channel and the meteorological conditions were similar to the September 2008.

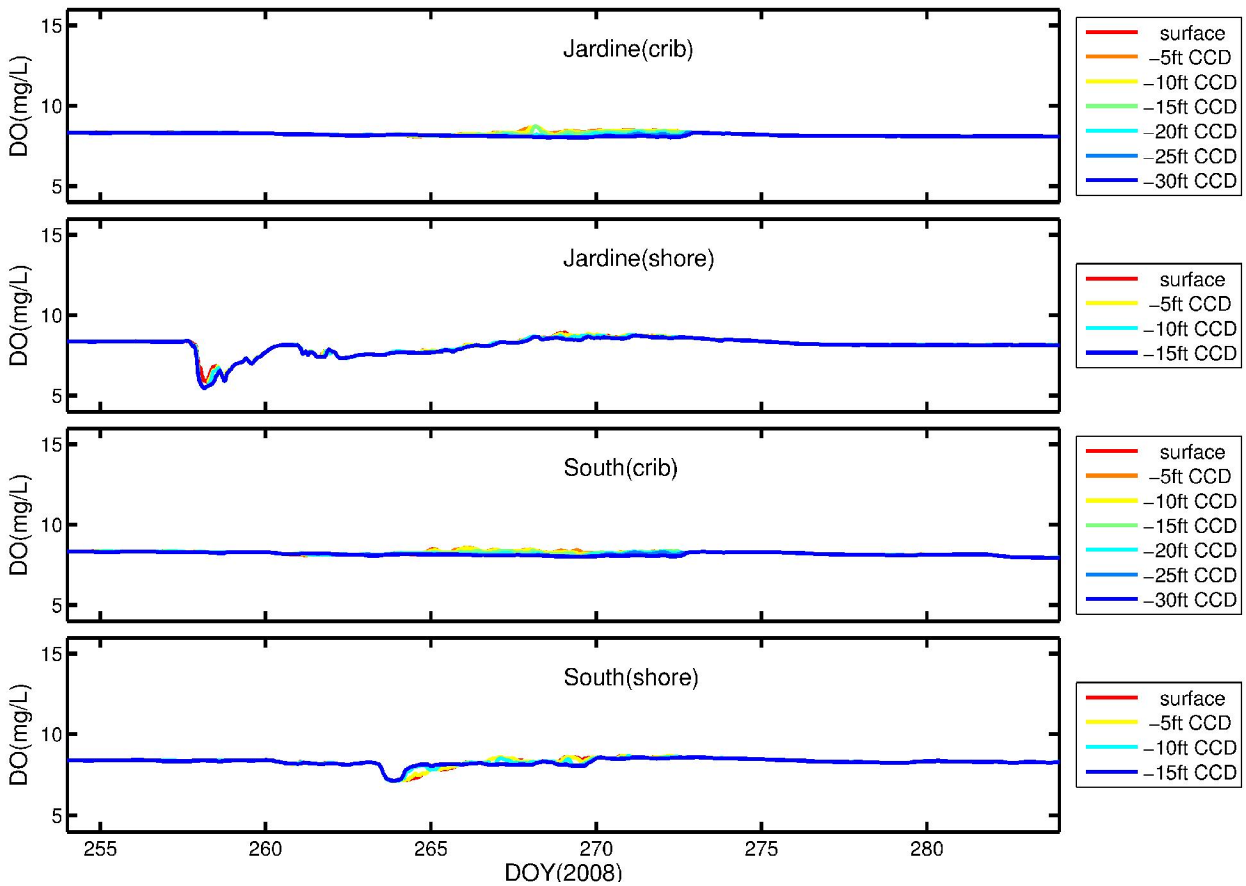

Figure 4.11 Concentration of dissolved oxygen at different depths at a few locations

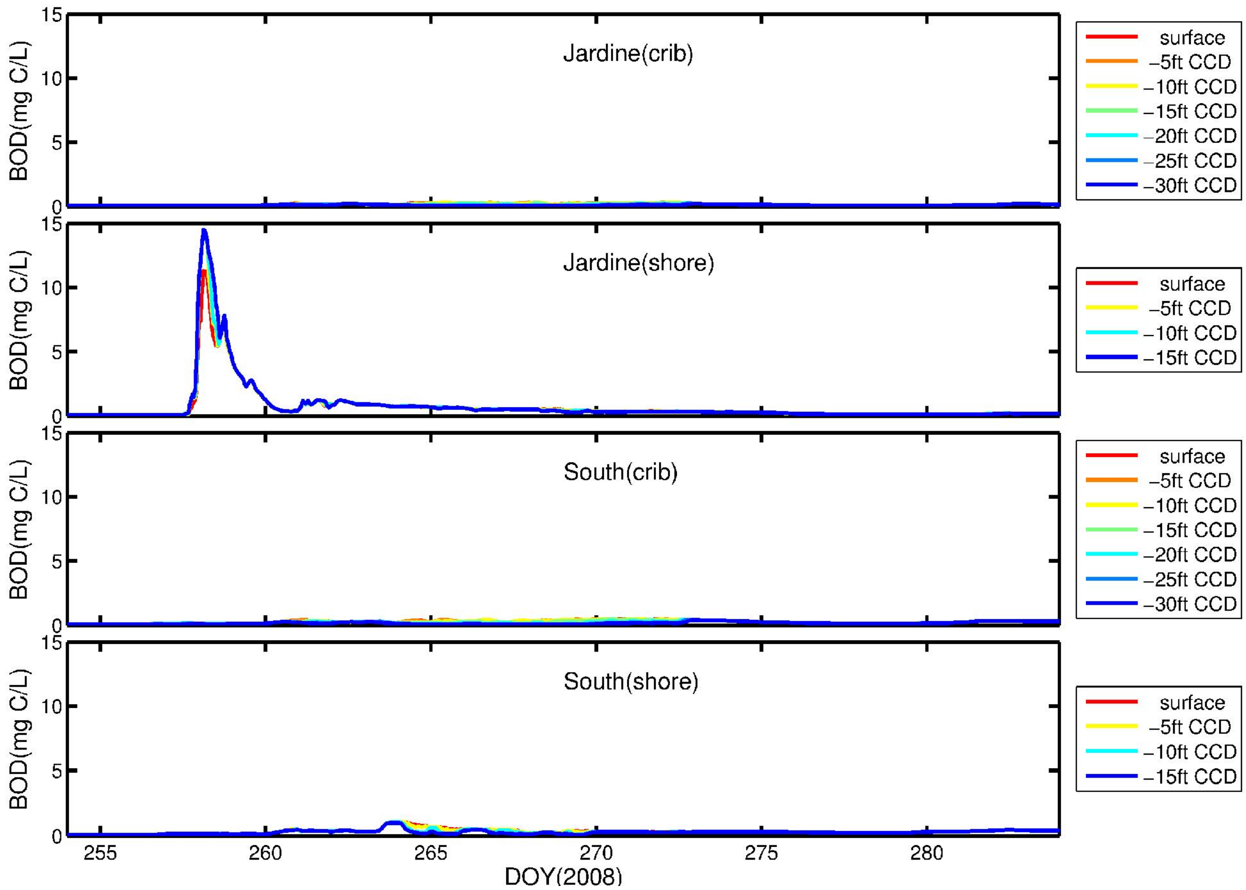

Figure 4.12 Concentration of oxygen demand at different depths at a few locations

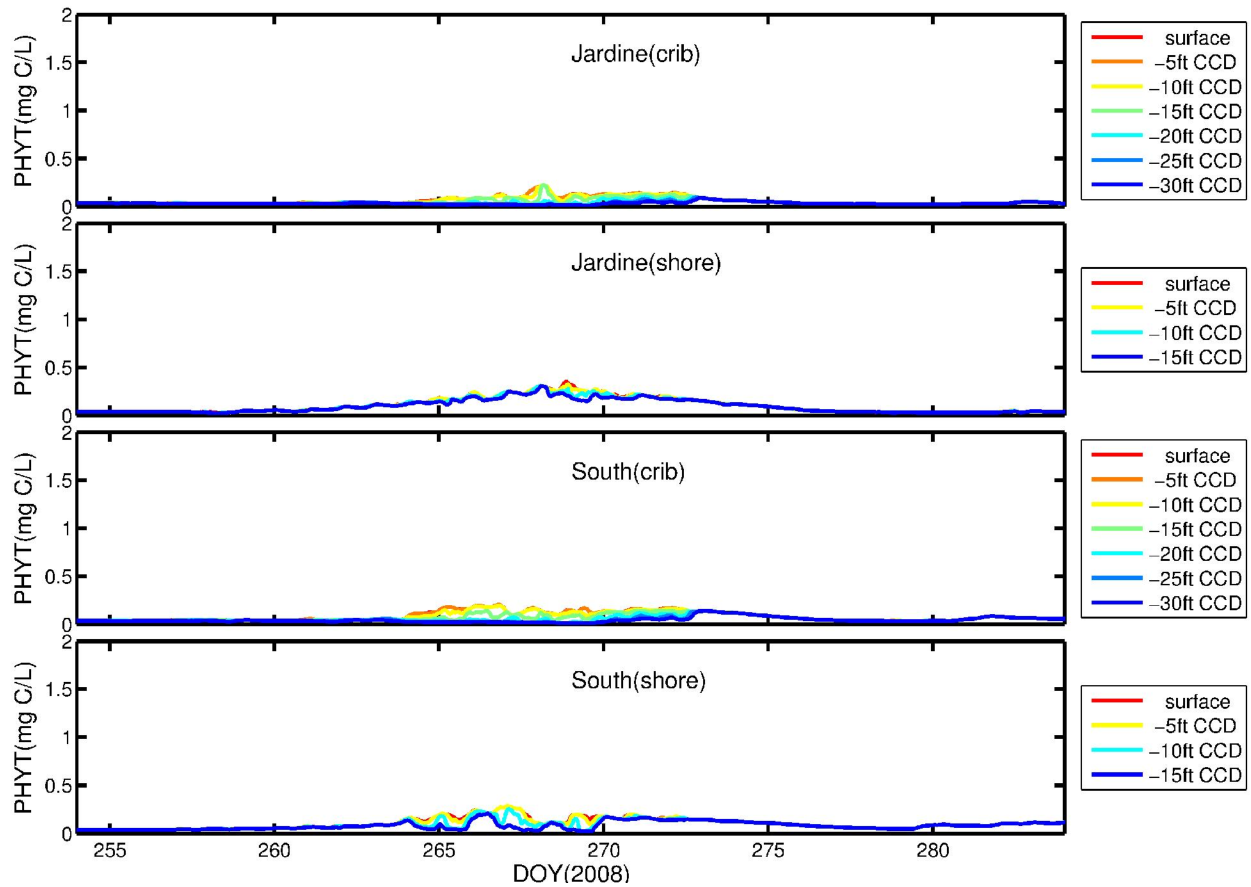

Figure 4.13 Concentration of phytoplankton at different depths at a few locations

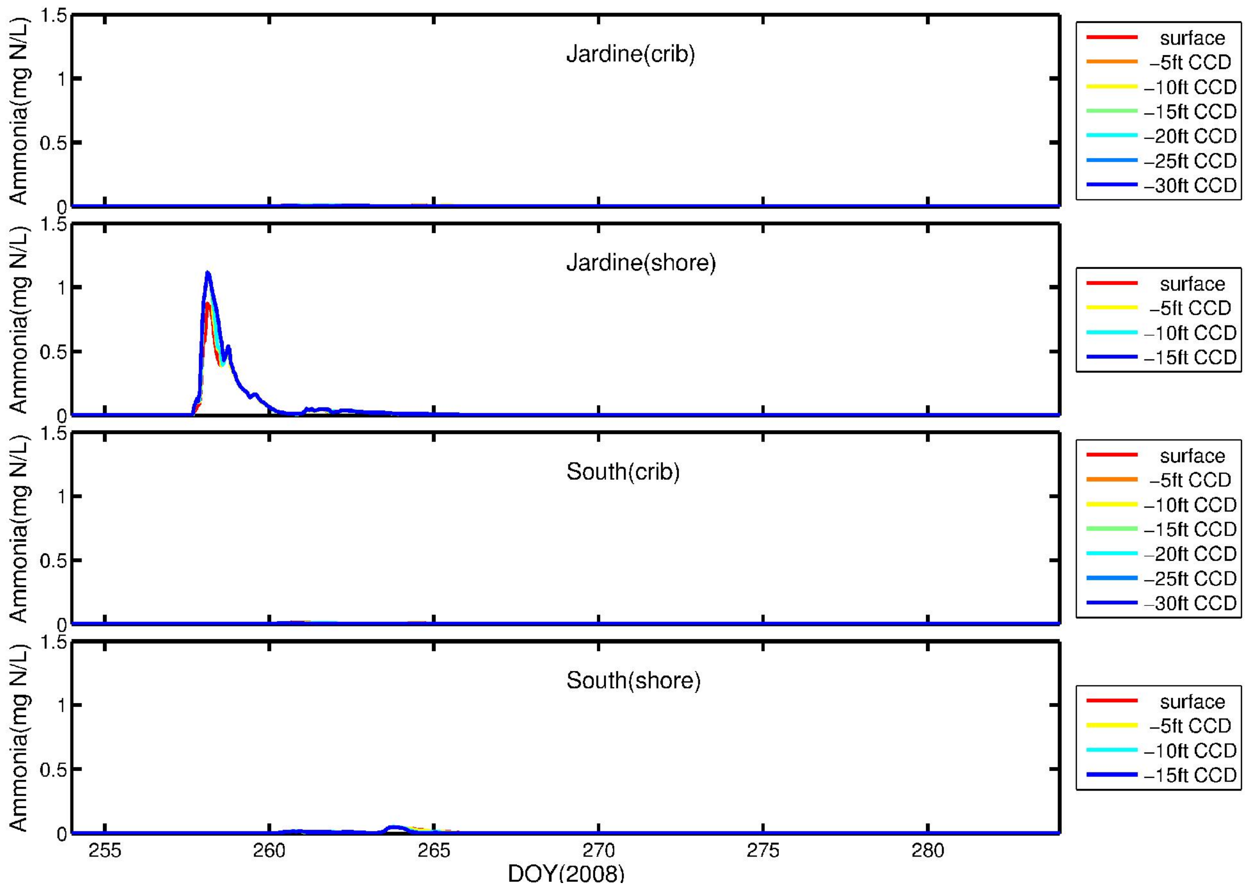

Figure 4.14 Concentration of ammonia at different depths at a few locations

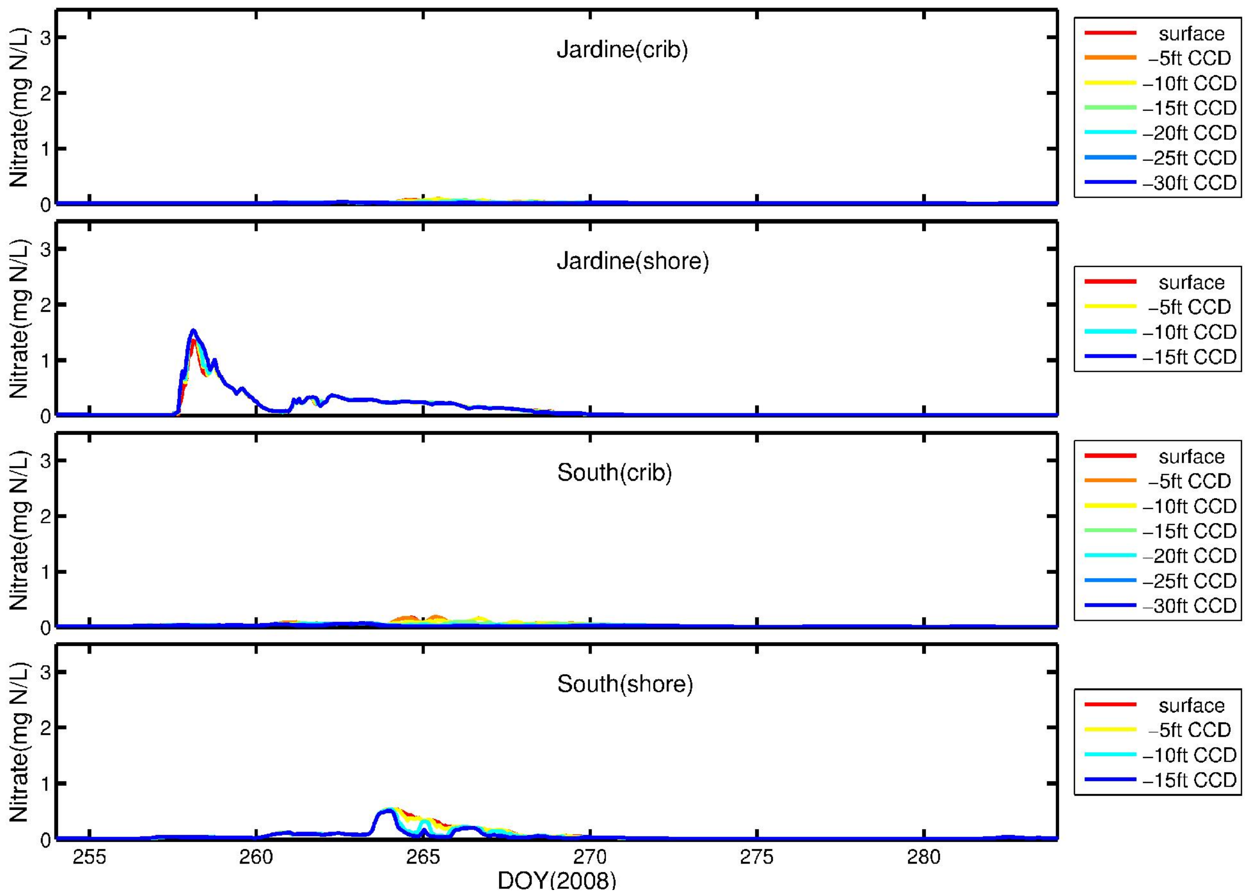

Figure 4.15 Concentration of nitrate at different depths at a few locations

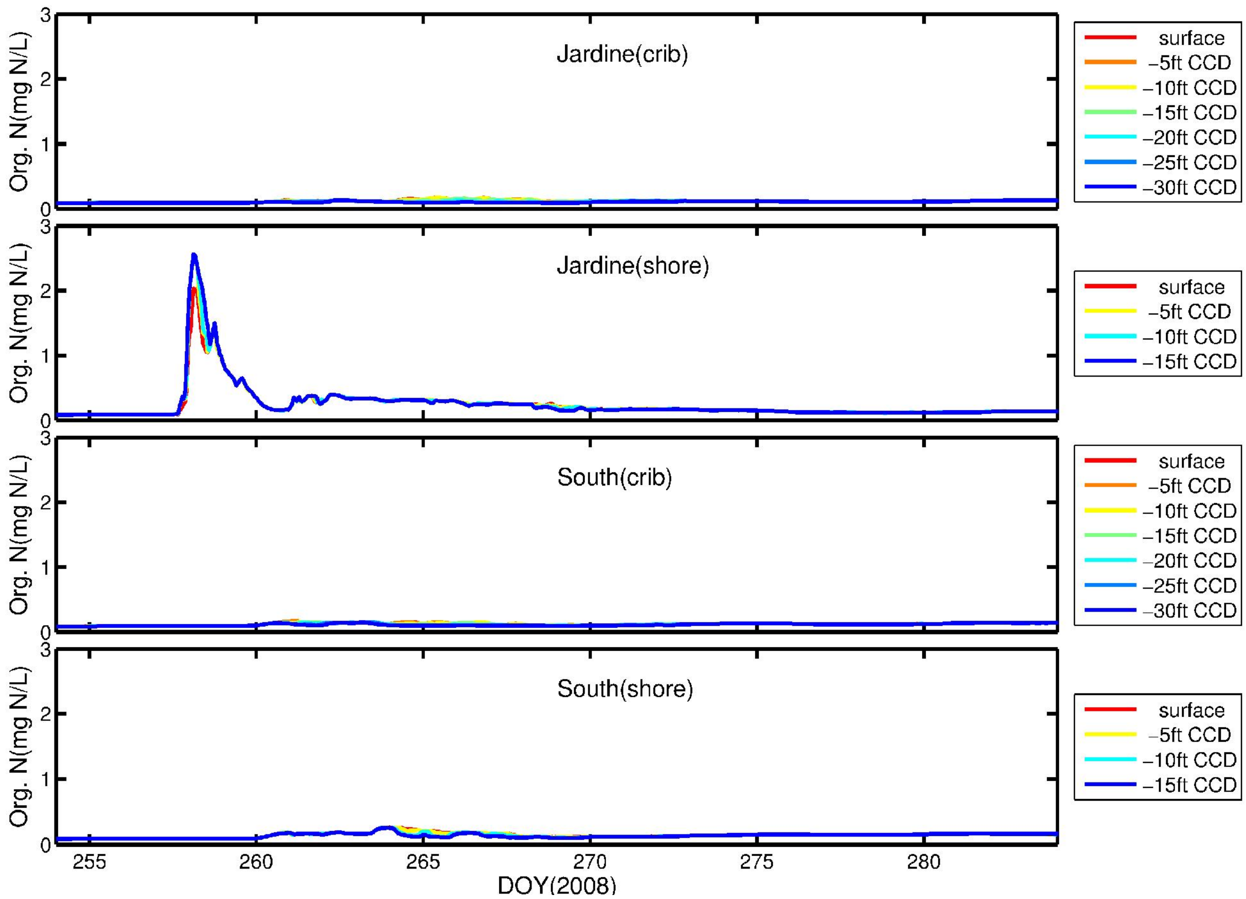

Figure 4.16 Concentration of organic nitrogen at different depths at a few locations

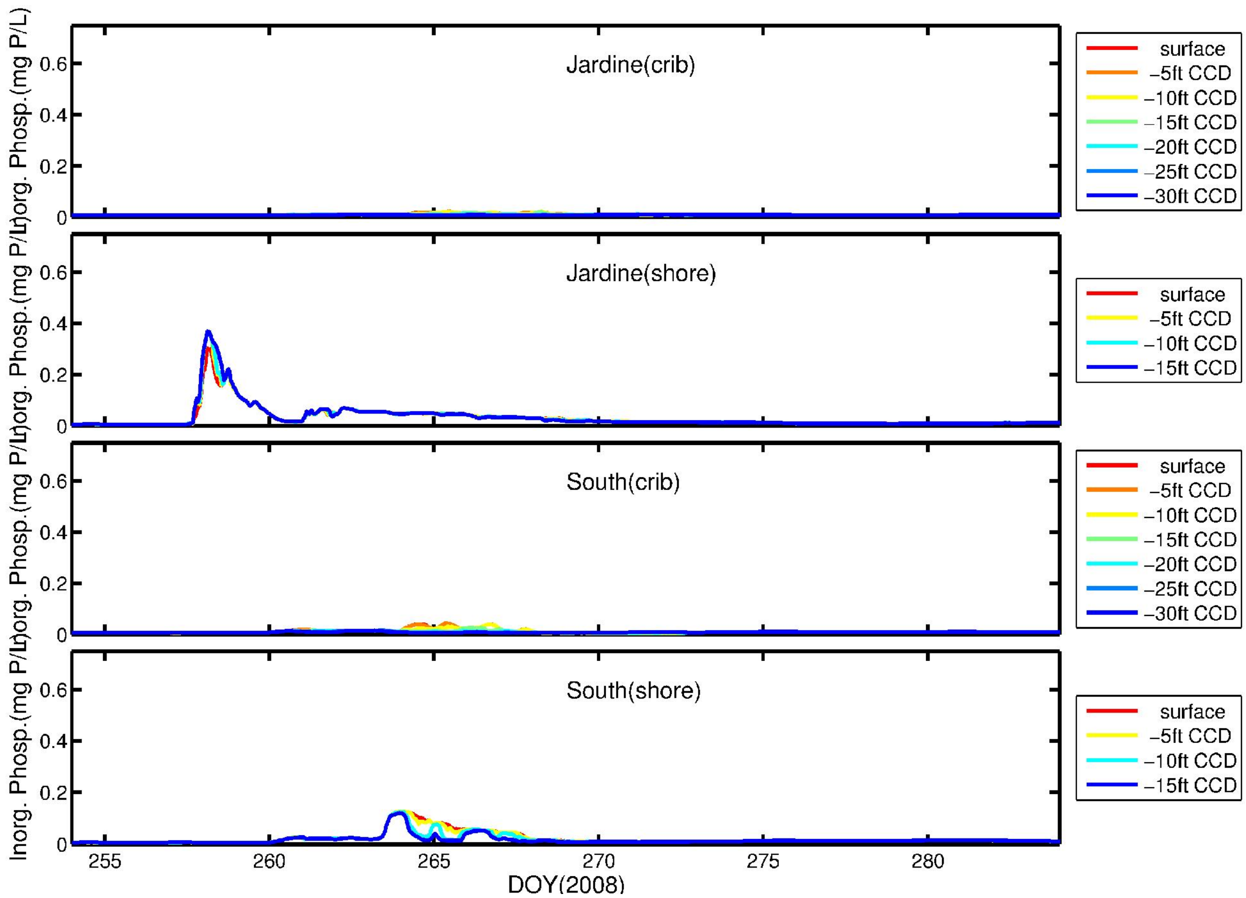

Figure 4.17 Concentration of ortho-phosphate at different depths at a few locations

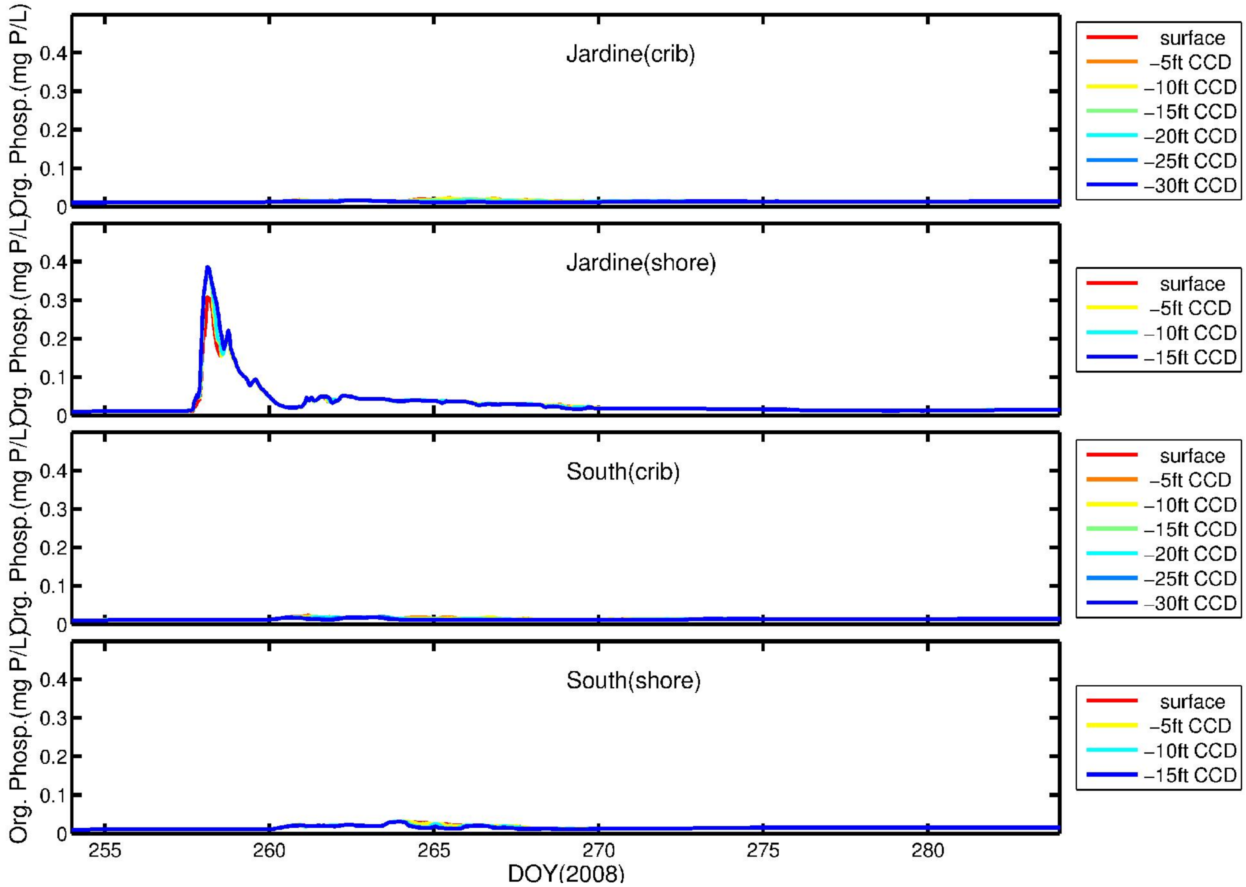

Figure 4.18 Concentration of organic phosphorous at different depths at a few locations

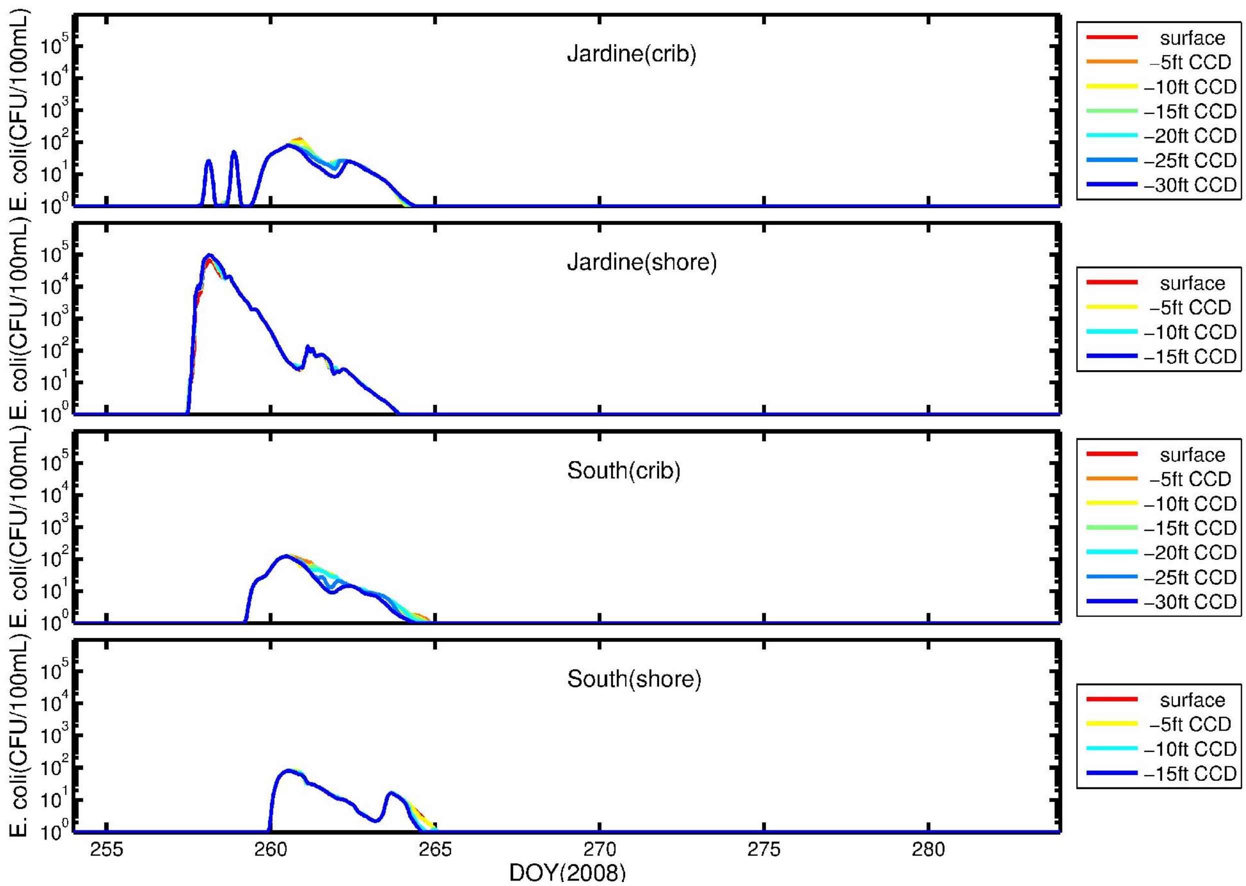

Figure 4.19 Concentration of *E. coli* at different depths at a few locations

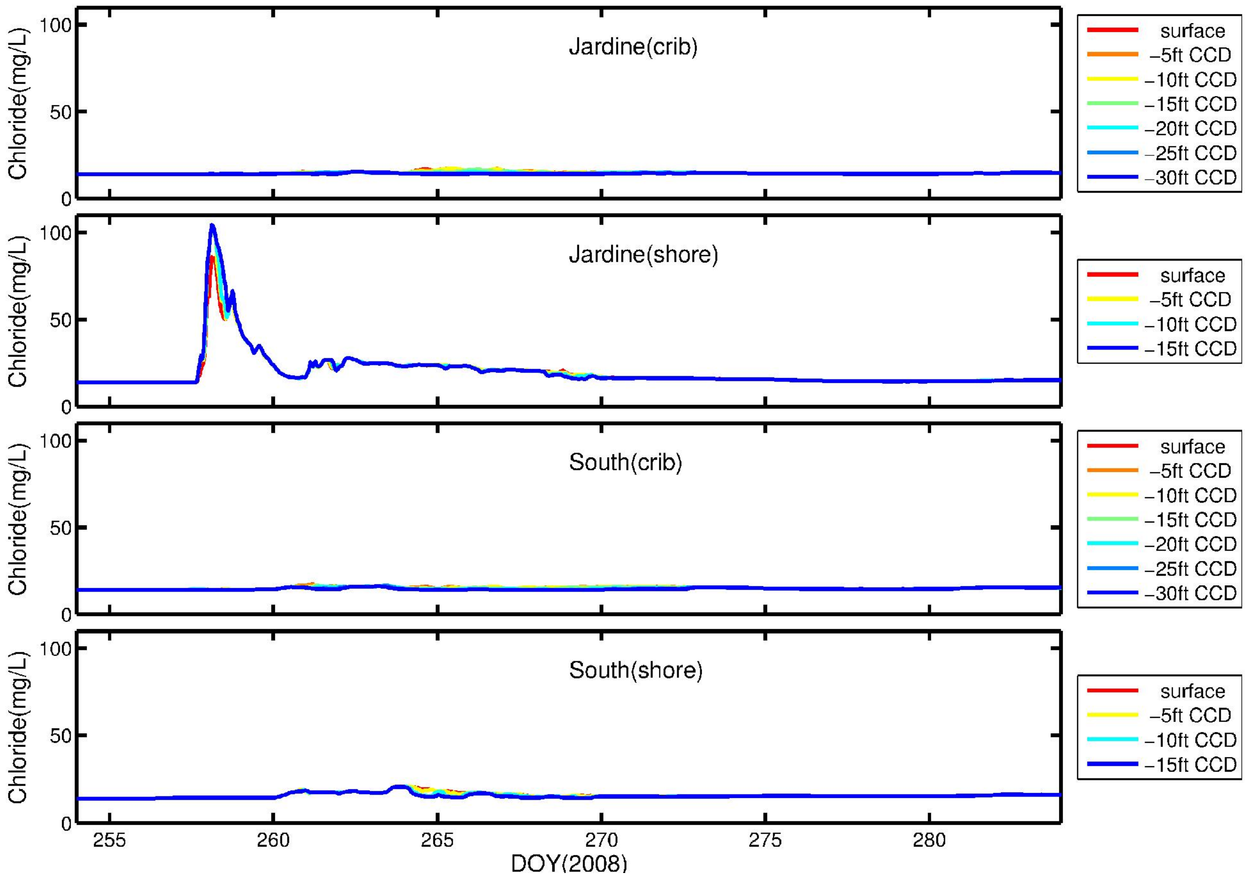

Figure 4.20 Concentration of chloride at different depths at a few locations

The mixing and transport of contaminants entering the nearshore environment in Lake Michigan is highly complex. The shape and size of the contaminant plume is determined by circulation patterns and mixing rates. The dynamic nature of these processes is not completely shown by the time-series plots presented in Chapter 3. Figure 4.11 (below) shows the spatial extent of the contaminant plumes entering southern Lake Michigan from the five outfalls (Wilmette, Chicago, Calumet, Indiana harbor Canal, Burns Ditch) during the September 2008 storm event modeled in Scenario S5 at the end of the simulation period. These plots show that the contaminants disperse very quickly and that the concentrations of contaminants in the plume reach ambient (lake background levels) within a few kilometers offshore. The spatial extent of the contaminant plumes depends on a number of factors including the volume of discharge, ratio of contaminant levels in the discharge to background levels and rate at which the contaminants are degraded/assimilated in the environment. Contour plots presented in Figure 4.11, suggest that nutrients entering the nearshore region are quickly dissipated and consumed. The concentrations of these variables therefore fall below water quality criteria for the nearshore waters very quickly. However, *E. coli* (indicative of fecal contamination of recreational waters) is significantly higher, longer and takes as much as 7 days after the discharge events to dissipate to background levels (as shown by Figure 4.9 for this scenario).

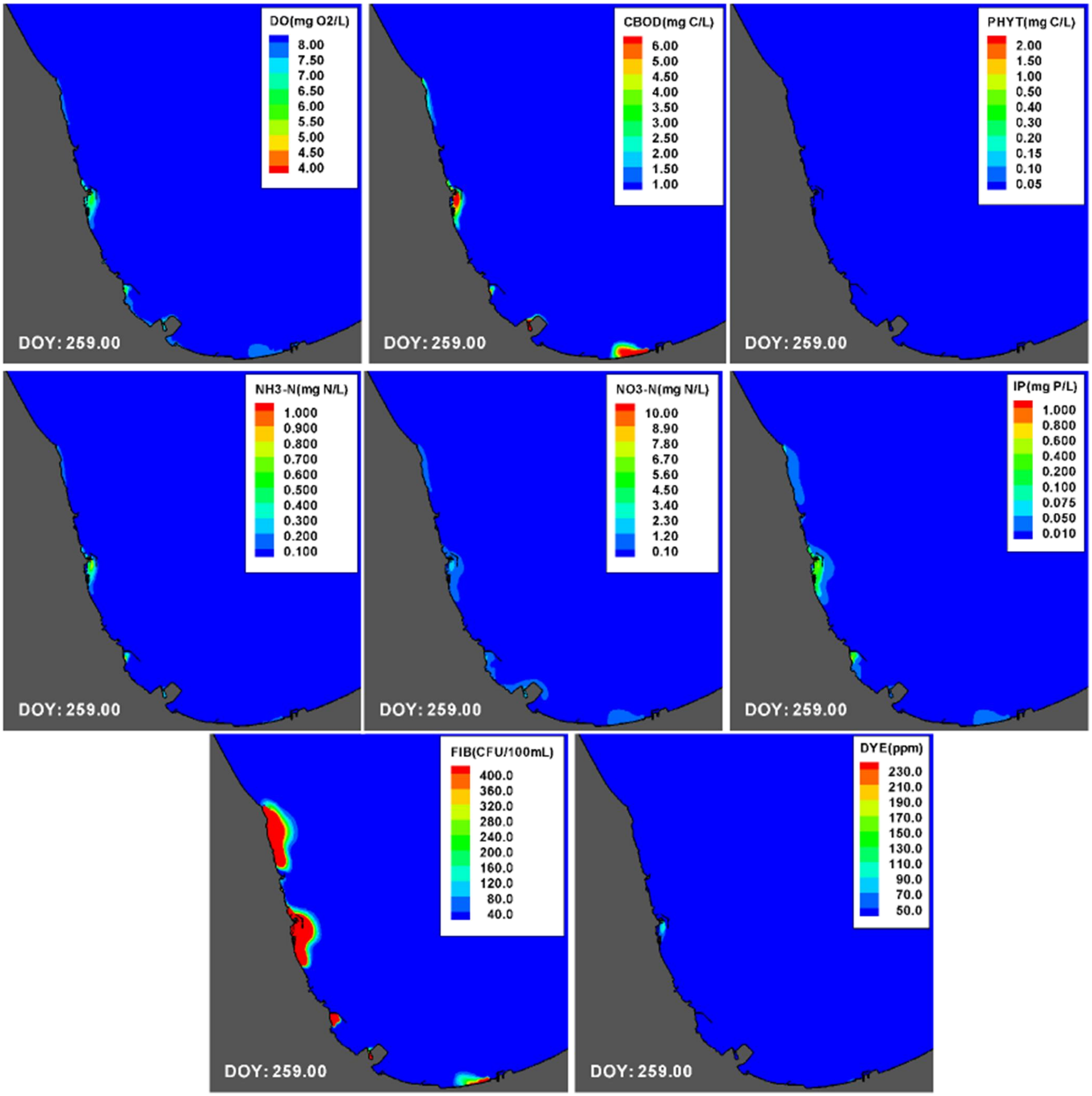

Figure 4.21 Contaminant plume shape and size on Julian Day (DOY) 259 based on Scenario 5 loading criteria

Chapter 5: Concluding Remarks

The principal objectives of this study were to assess the impacts of discharges from outfalls in southern Lake Michigan on the nearshore water quality as well as on lake-wide circulation and concentration levels. We have used a numerical water quality model coupled to a hydrodynamic model to simulate the transport, mixing and biogeochemical processes that impact the concentrations of water quality variables in the water column. The models were tested using observations from a field study conducted in Southern Lake Michigan near the Burns Ditch outfall. The results of the testing (validation) experiments presented in Chapter 3 demonstrate that the model is able to simulate temperature and currents in the nearshore with a high degree of accuracy. The model is also able to predict the variation in contaminant concentrations close to the outfalls. However, some of the peak concentrations could not be accurately resolvedby the model. This could be due to the low-resolution of observations available at the source (Burns Ditch) as well as at the sampling point (WQ1). Simulation results reveal a high degree of vertical variability in the concentrations of water quality variables modeled, however representative water sampling at three different depths in the water column might be unable to accurately estimate the average concentration at any point. In addition, several processes are not included in the numerical water quality model, including wave resuspension of nutrients from the sediment, spatially variable sediment oxygen demand, discharge from overland flow and other minor outfalls, distributed sources along the shoreline etc. All these processes are likely to add to the uncertainty in the model predictions and accounting for these processes/ sources better could improve the water quality models accuracy.

Several scenarios of interest were identified and the results of these simulations are presented in Chapter 3. The results of these simulations are presented as time-series of the concentration of water quality variables at different intake locations. Comparing the values at the intake locations with candidate benchmarks for water quality thresholds, it is clear that contaminant concentrations fall quickly to background levels due to the mixing and transport in the nearshore region. Nutrient inputs into the nearshore significantly increase the primary production and algal biomass production in the water column. This can be observed clearly by comparing the phytoplankton concentrations predicted by the baseline seasonal simulation (Scenario 1) with long-term continuous release simulations (Scenarios 2 and 3).

The severe loading conditions simulated in the episodic release scenarios (S4 and S5) reveal that the impact of a large discharges of contaminants into the nearshore – such as the one observed during the September 2008 storm – is greatest at the locations closest to where the discharges enter the nearshore. However, physical and biological processes quickly reduce the levels of contaminants in the water column to levels that are below candidate benchmark levels. On average, the impact of the storm was completely dissipated in about 7-10 days.

Model Assumptions and Limitations

The processes that determine the transport, dissipation, and degradation of contaminants in the water column are highly complex. Some of the simplifications in our modeling include the following: (a) sediment and particle processes as well as waves, wave-current interactions and their influence on particle processes and contaminant concentrations are not accounted for (b) spatially variable sediment oxygen demand and distributed sources and their impact on water quality are not described by the models. A potential impact of these simplifying assumptions is that some of the water quality variables such as Chloride or Nitrate may accumulate over time. A continuous simulation (e.g., over decades) based on a more detailed modeling that takes these processes into account may provide additional information about the long-term effect of the discharges into Lake Michigan.

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Appendix-A

1. Hydrodynamic Model

The hydrodynamic model used in this study is the Finite-Volume Coastal Ocean Model (FVCOM, [*Chen et al.*, 2003]) which solves the three-dimensional hydrodynamic equations in their primitive form. Since Lake Michigan is a large freshwater lake and density differences are not a significant driver of circulation in the lake, a model such as FVCOM that assumes hydrostatic distribution of pressure in the vertical is expected to describe the hydrodynamics well. The effect of temperature differences on momentum is included by invoking the Boussinesq approximation. Equations (1-3) below show the momentum transport equations solved by the hydrodynamic model. The continuity equation (4), and the temperature (5) equations are also given.

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}-fv = -\frac{1}{\rho_o}\frac{\partial P}{\partial x}+\frac{\partial}{\partial x}\left(A_m\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(A_m\frac{\partial v}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_m\frac{\partial u}{\partial z}\right) \quad (1)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}+fu = -\frac{1}{\rho_o}\frac{\partial P}{\partial y}+\frac{\partial}{\partial x}\left(A_m\frac{\partial v}{\partial x}\right)+\frac{\partial}{\partial y}\left(A_m\frac{\partial v}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_m\frac{\partial v}{\partial z}\right) \quad (2)$$

$$\frac{\partial P}{\partial z} = -\rho g \quad (3)$$

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z} = 0 \quad (4)$$

$$\frac{\partial \theta}{\partial t}+u\frac{\partial \theta}{\partial x}+v\frac{\partial \theta}{\partial y}+w\frac{\partial \theta}{\partial z} = \frac{\partial}{\partial x}\left(A_h\frac{\partial \theta}{\partial x}\right)+\frac{\partial}{\partial y}\left(A_h\frac{\partial \theta}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_h\frac{\partial \theta}{\partial z}\right) \quad (5)$$

Here, $(u, v, w)$are the velocity components in the Cartesian (x, y, z) coordinates; f is the Coriolis component of force due to the transformation of rotating frame of reference to the inertial frame of reference; g is acceleration due to gravity; P is the fluid pressure; ρ and ρ_o are the actual and reference densities; K_h $(K_m)$and $A_h(A_m)$ are the vertical and horizontal eddy diffusivities (viscosities) that are calculated using the Mellor-Yamada and Smagorinsky models for turbulence closure respectively.

2. Numerical water quality model

The water quality module in FVCOM is based on the three-dimensional water quality analysis and simulation program (WASP5) that was originally developed by [*Ambrose et al.*, 1993]. It simulates the nitrogen and phosphorous cycles, phytoplankton dynamics as well as dissolved oxygen. In all there are eight distinct water quality variables that are solved: dissolved oxygen (DO), phytoplankton (PHYT), carbonaceous biochemical oxygen demand (CBOD), ammonium nitrogen (NH_4), nitrate and nitrite nitrogen (NO_3), ortho-phosphorous or inorganic phosphorous (OPO_4), organic nitrogen (ON), and organic phosphorous (OP). The individual water quality components were solved using the advection diffusion equation (1) with the component dependent internal source/sink (S) calculated using Equations (7-15).

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}+w\frac{\partial C}{\partial z}=\frac{\partial}{\partial x}\left(A_h\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(A_h\frac{\partial C}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_h\frac{\partial C}{\partial z}\right)+S+W_0 \qquad (6)$$

Here, C is the concentration (mass per unit volume) of the water quality component, S is the net of various internal sources and sinks depending on the component being modeled, $W_0$is the external loading from rivers, outfalls and non-point sources. u, v, w are the velocity components in the Cartesian x, y, z directions.

The equations used to calculate the internal sources and sinks for the specific water quality components are given in Equations 7-15. Chloride component is modeled as a tracer without any internal sources or sinks.

Dissolved Oxygen (DO)

$$S_1 = k_{r1}\theta_{r1}^{(T-20)}(C_s - C_1) - k_{d1}\theta_{r1}^{(T-20)}\frac{C_1C_3}{K_{BOD} + C_1} - \frac{32}{12}k_{r2}\theta_{r1}^{(T-20)}C_2$$

$$- \frac{32}{14}2k_{ni}\theta_{ni}^{(T-20)}\frac{C_1C_4}{K_{nitr} + C_1} + G_P\left[\frac{32}{12} + \frac{48}{14}a_{nc}\left(1 - P_{NH_4}\right)\right]C_2$$

$$- \frac{SOD}{D}\theta_{SOD}^{(T-20)} - k_{r3} \tag{7}$$

Phytoplankton (PHYT)

$$S_2 = G_PC_2 - D_PC_2 - \frac{\omega_2 S}{D}C_2 \tag{8}$$

Growth rate of phytoplankton (G_P) is a function of temperature (T) incident radiation and nutrient availability. In the model it has been calculated using:

$$G_P = k_{gr}\theta_{gr}^{(T-20)}f_1(N)f_2(I)$$

Here, the nutrient limitation factor $f_1(N)$is determined based on the calculated concentration of net available nitrogen (ammonium, nitrate, and nitrite) phosphorous (orthophosphate) assuming a Michaelis-Menten relationship based on limiting concentration being either nitrogen or phosphorous. The term $f_2(I)$ is the light limitation factor.

$$f_1(N) = \min\left(\frac{C_4 + C_5}{K_{mN} + C_4 + C_5}, \frac{C_6}{K_{mP} + C_6}\right)$$

While ammonium and nitrate are both nitrogen sources for phytoplankton growth, preference is given to the ammonium form for nitrogen. This is included in the model as the ammonium preference factor$\left(P_{NH_4}\right)$.

$$P_{NH_4} = \frac{C_4C_5}{(K_{mN} + C_4)(K_{mN} + C_5)} + \frac{C_4K_{mN}}{(C_4 + C_5)(K_{mN} + C_5)}$$

Death of phytoplankton due to viral lysis, grazing by zooplankton, and endogenous respiration is calculated using:

$$D_P = \left(k_{r2} + k_{par}k_{grz}\right)\theta_{gr}^{(T-20)}$$

Carbonaceous biochemical oxygen demand (CBOD)

$$S_3 = a_{oc}\left(k_{par} + k_{grz}\right)C_2 - k_{d1}\theta_{d1}^{(T-20)}\frac{C_1C_3}{K_{BOD} + C_1} - \frac{\omega_{3S}(1 - f_{D3})}{D}C_3$$
$$- \frac{5}{4} \times \frac{32}{12} \times \frac{12}{14}k_{dn}\theta_{dn}^{(T-20)}\frac{C_5K_{NO_3}}{K_{NO_3} + C_1} \tag{9}$$

Ammonium nitrogen (NH_4)

$$S_4 = a_{nc}D_P(1 - f_{on})C_2 + k_{m1}\theta_{m1}^{(T-20)}\frac{C_2C_7}{K_{mPc} + C_2} - a_{nc}G_PP_{NH_4}C_2$$
$$- k_{ni}\theta_{ni}^{(T-20)}\frac{C_1C_4}{K_{NITR} + C_1} + B_1 \tag{10}$$

Nitrate and nitrite nitrogen (NO_3)

$$S_5 = k_{ni}\theta_{ni}^{(T-20)}\frac{C_1C_4}{K_{NITR} + C_1} - a_{nc}G_P\left(1 - P_{NH_4}\right)C_2$$
$$- k_{dn}\theta_{dn}^{(T-20)}\frac{C_5K_{NO_3}}{K_{NO_3} + C_1} + B_2 \tag{11}$$

Ortho-phosphorous (OPO_4)

$$S_6 = a_{pc}D_P\left(1 - f_{op}\right)C_2 + k_{m2}\theta_{m2}^{(T-20)}\frac{C_2C_8}{k_{mPc} + C_2} - a_{pc}G_PC_2 + B_3 \tag{12}$$

Organic Nitrogen (ON)

$$S_7 = a_{nc} D_P f_{on} C_2 - k_{m1} \theta_{m1}^{(T-20)} \frac{C_2 C_7}{K_{mPc} + C_2} - \frac{\omega_{7S}(1 - f_{D7})}{D} C_7 \tag{13}$$

Organic Phosphorous (OP)

$$S_8 = a_{pc} D_P f_{op} C_2 - k_{m2} \theta_{m2}^{(T-20)} \frac{C_2 C_8}{K_{mPc} + C_2} - \frac{\omega_{8S}(1 - f_{D8})}{D} C_8 \tag{14}$$

Fecal Indicator bacteria (FIB)

$$S_9 = C_9 \left(k_d + k_I I + \omega_9 f_{pFIB}\right) \theta_{FIB}^{(T-20)} \tag{15}$$

All the terms used in calculating the internal sources and sinks are defined in Table 2.1

The values of parameters were chosen based on the information available in literature and adjusting them based on the validation/testing dataset collected in southern Lake Michigan during summer 2012 field study.

The oxygen reaeration rate $k_{r1}$was chosen as in the case of [*Zheng et al.*, 2004] as the maximum of flood-induced reaeration and wind-induced reaeration. The dissolved oxygen saturation concentration $C_S$for freshwater systems was determined based on temperature (T) using:

$$\ln C_S = -139.34 + (1.5757 \times 10^5)T^{-1} - (6.6423 \times 10^7)T^{-2} + (1.2438 \times 10^{10})T^{-3} - (8.6219 \times 10^{11})T^{-4}$$

Sediment oxygen demand (SOD)is due to various biological and chemical reactions that take place on the surface of the sediment layer and within the sediment layer. This is dependent on a number of factors including the amount of sunlight reaching the bottom sediment layer, microbiological activity, temperature, nutrient concentrations, and detritus levels in the sediment layer.

Table 1 Definition and value of the parameters used in the water quality model

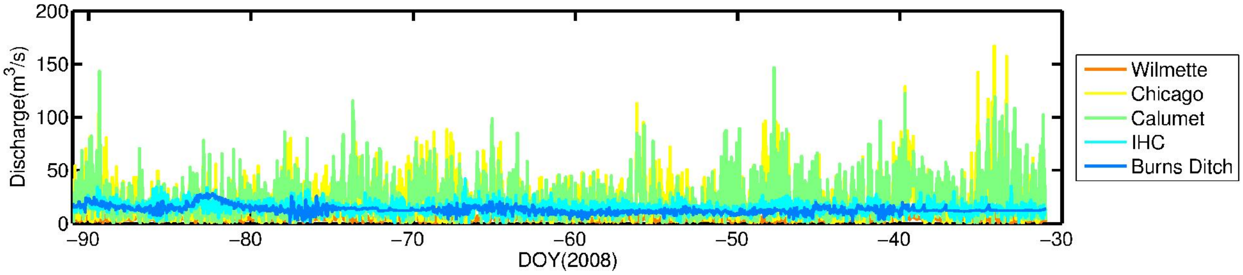
Name	Description	Value
k_{r1}	Reaeration rate (day^{-1})	$\max(k_f, k_w)$
k_f	Flow induced reaeration rate (day^{-1})	O'Connor method.
k_w	Wind-induced reaeration rate (day^{-1})	Covar method
k_{d1}	CBOD de-oxygenation rate (day^{-1})	.10
k_{ni}	Nitrification rate (day^{-1})	.09
k_{r2}	Phytoplankton respiration rate (day^{-1})	.10
k_{r3}	Bacterial respiration rate (mg O_2/day^{-1})	0.0
k_{dn}	De-nitrification rate (day^{-1})	.09
k_{gr}	Phytoplankton optimum growth rate (day^{-1})	2.5
$k_{par} + k_{grz}$	Phytoplankton basal loss rate (day^{-1})	.04
k_{m1}	Organic nitrogen mineralization rate (day^{-1})	.075
k_{m2}	Organic phosphorous mineralization rate (day^{-1})	.22
θ_{r1}	Temperature adjustment for reaeration rate	1.028
θ_{d1}	Temperature adjustment for de-oxygenation rate	1.047
θ_{ni}	Temperature adjustment for nitrification rate	1.080
θ_{r2}	Temperature adjustment for phytoplankton respiration rate	1.080
θ_{dn}	Temperature adjustment for de-nitrification rate	1.080

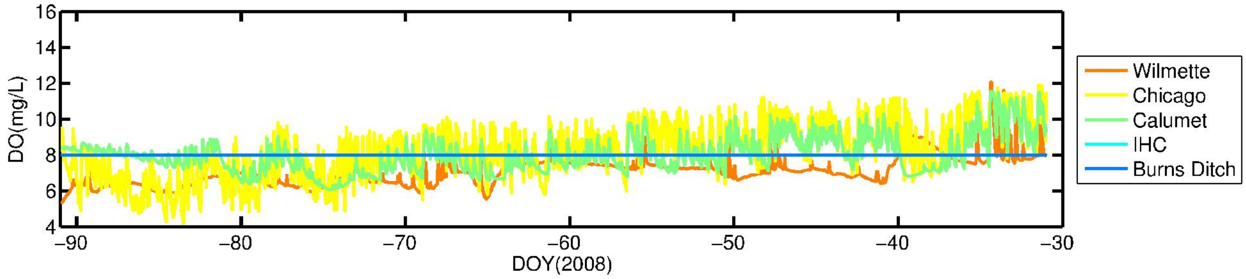
θ_{gr}	Temperature adjustment for phytoplankton growth rate	1.066
θ_{mr}	Temperature adjustment for phytoplankton death rate	1.0
θ_{m1}	Temperature adjustment for org. nitrogen mineralization rate	1.080
θ_{m2}	Temperature adjustment for org. phosphorous mineralization rate	1.080
θ_{SOD}	Temperature adjustment for SOD	1.080
SOD	Sediment oxygen demand ($gm^{-2}.day^{-1}$)	.2
K_{BOD}	Half-saturation conc. for oxygen limitation of CBOD oxidation (mg O_2 L^{-1})	.5
K_{NITR}	Half-saturation conc. for oxygen limitation of nitrification (mg O_2 L^{-1})	.5
K_{NO_3}	Half-saturation conc. for oxygen limitation of de-nitrification (mg O_2 L^{-1})	.10
K_{mN}	Half-saturation conc. for nitrogen uptake (µg N L^{-1})	25.0
K_{mP}	Half-saturation conc. for phosphorous uptake (µg P L^{-1})	1.0
k_{mPc}	Half-saturation conc. for phytoplankton limitation (mg C L^{-1})	1.0
ω_{2S}	Settling velocity for phytoplankton (m/d)	.5
ω_{2S}	Settling velocity of CBOD (m/d)	.5
ω_{2S}	Settling velocity of particulate organic nitrogen (m/d)	.5
ω_{2S}	Settling velocity for particulate organic phosphorous (m/d)	.5

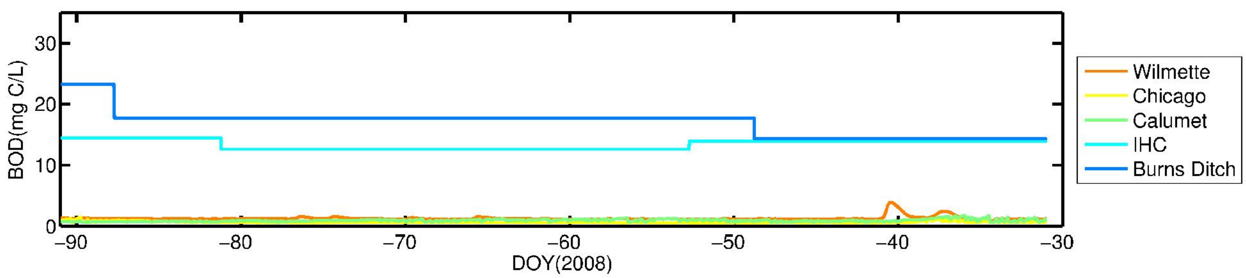
f_{D3}	Fraction of dissolved CBOD	.5
f_{D7}	Fraction of dissolved organic nitrogen	1.0
f_{D8}	Fraction of dissolved organic phosphorous	1.0
f_{on}	Fraction of dead and respired phytoplankton recycled to organic nitrogen pool	.65
f_{op}	Fraction of dead and respired phytoplankton recycled to organic phosphorous pool	.65
a_{nc}	Phytoplankton nitrogen-carbon ratio	.25
a_{pc}	Phytoplankton phosphorous-carbon ratio	.025
a_{oc}	Ratio of oxygen to carbon	32/12
k_e	Light attenuation coefficient (m^{-1})	1.0
I_S	Optimal light intensity	250.0

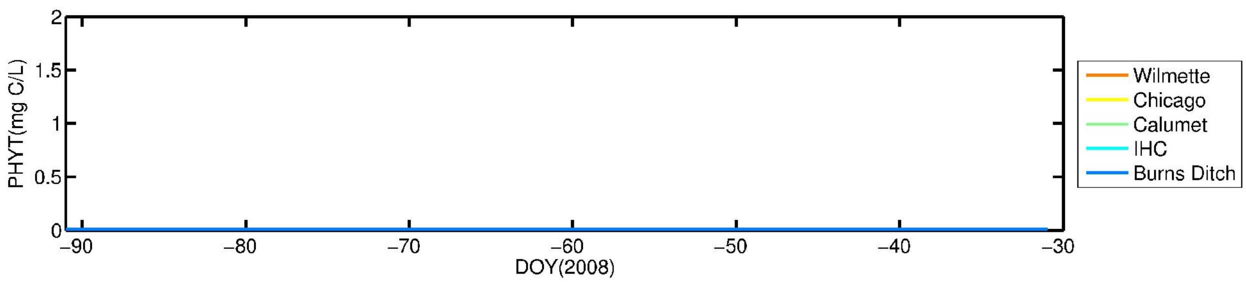
Appendix -B: Input Time Series to the Numerical Models

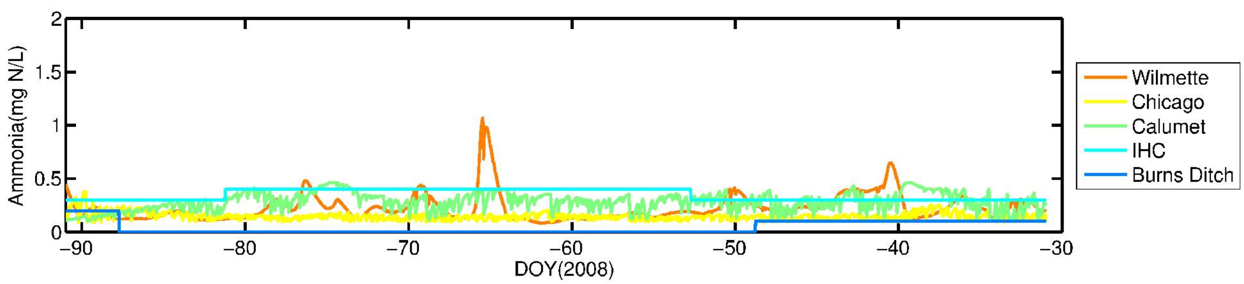
Scenario 2: Sept2007-November2007

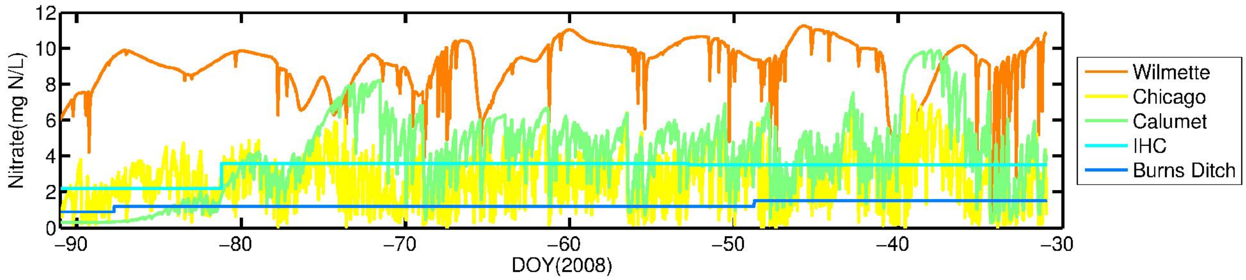


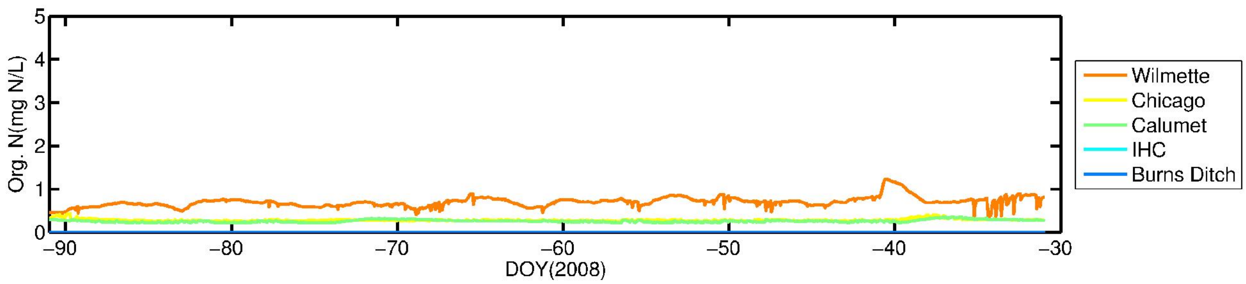


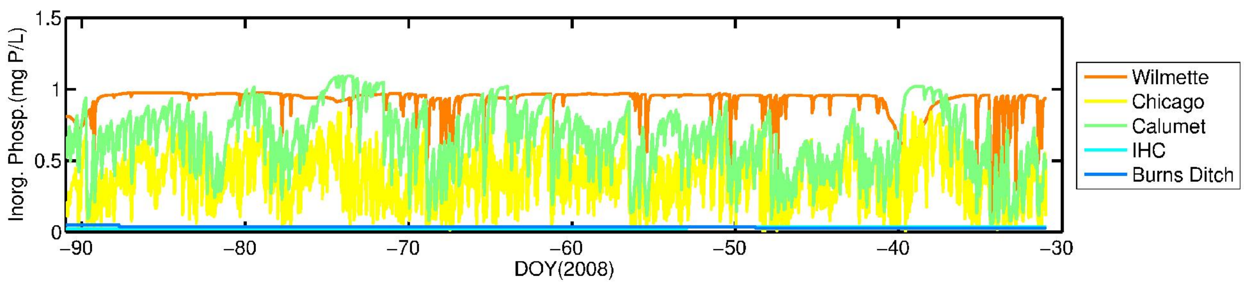







Nitrate(mg N/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch


Org. N(mg N/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch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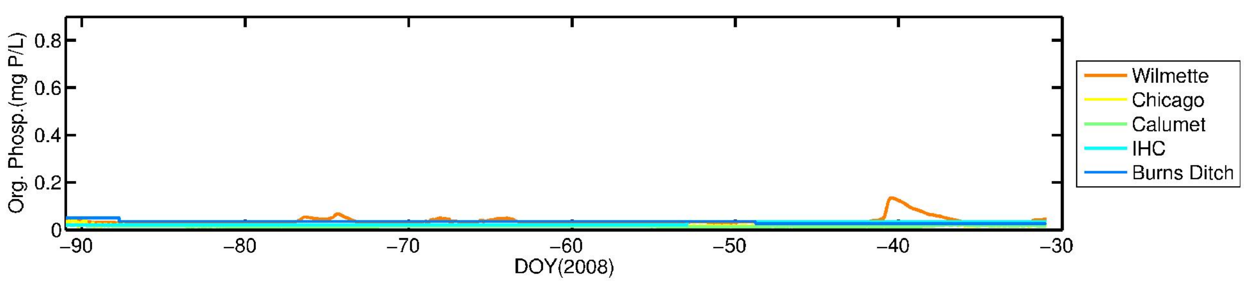
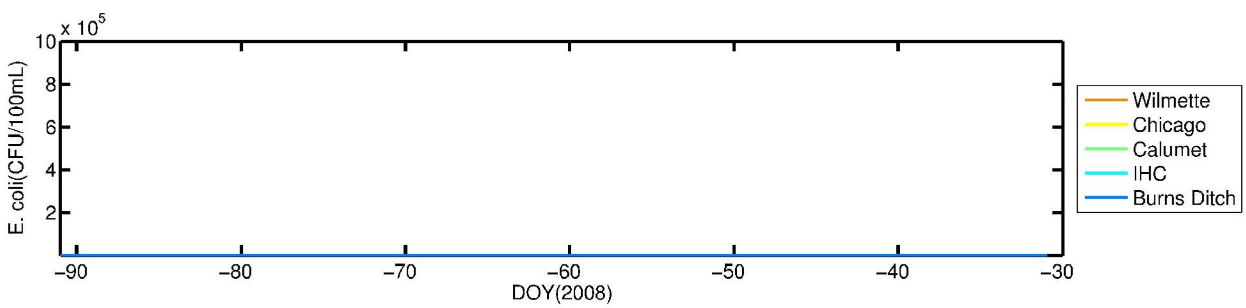
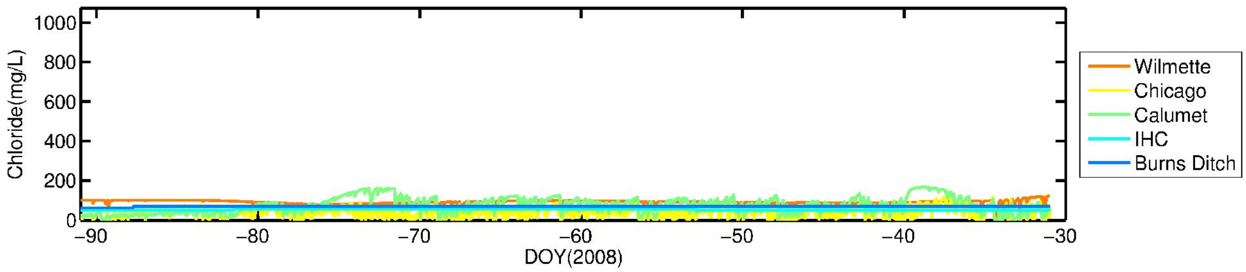
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

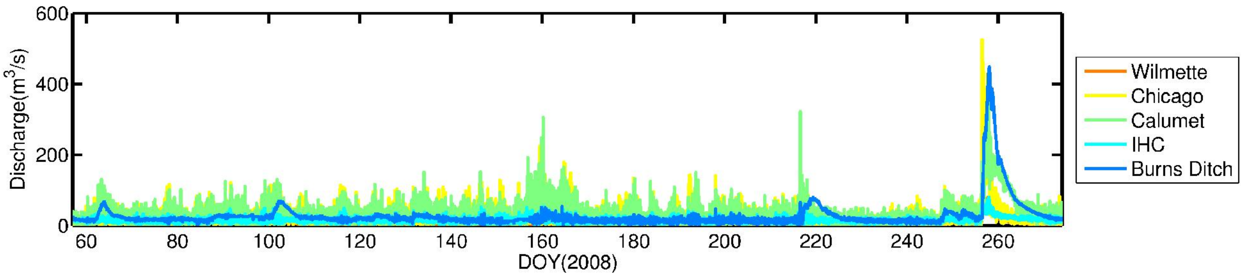

Org. Phosp.(mg P/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

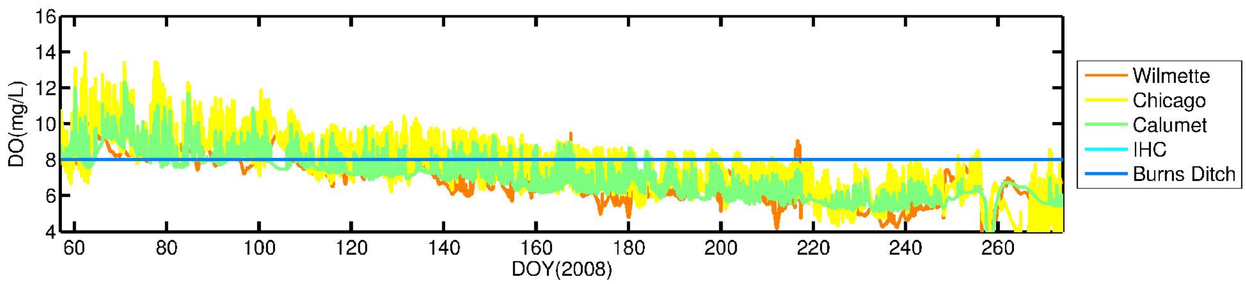

x 10^5
E. coli(CFU/100mL)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

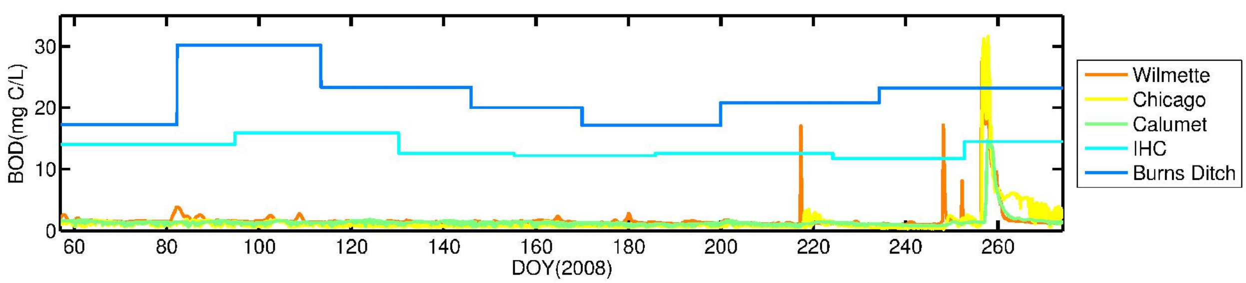


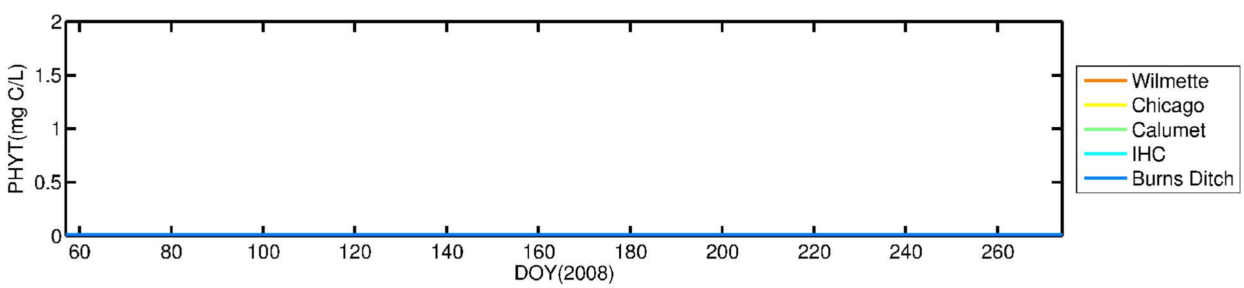
1000
800
600
400
200
0
Chloride(mg/L)
−90
−80
−70
−60
−50
−40
−30
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

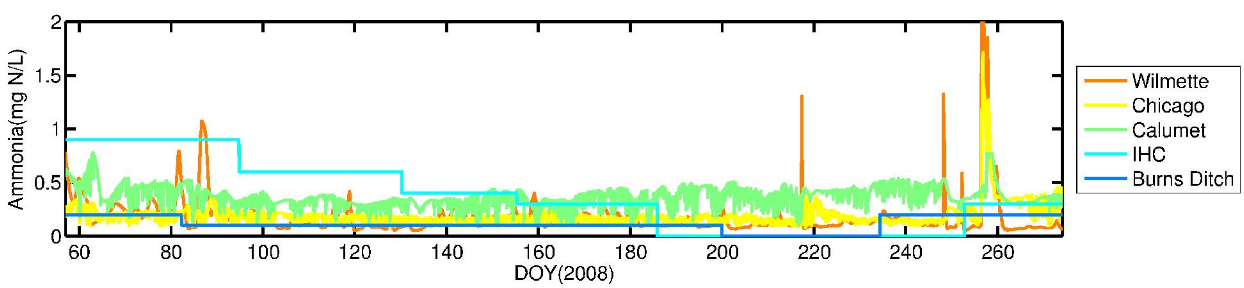
Scenario 2: March2008-September2008

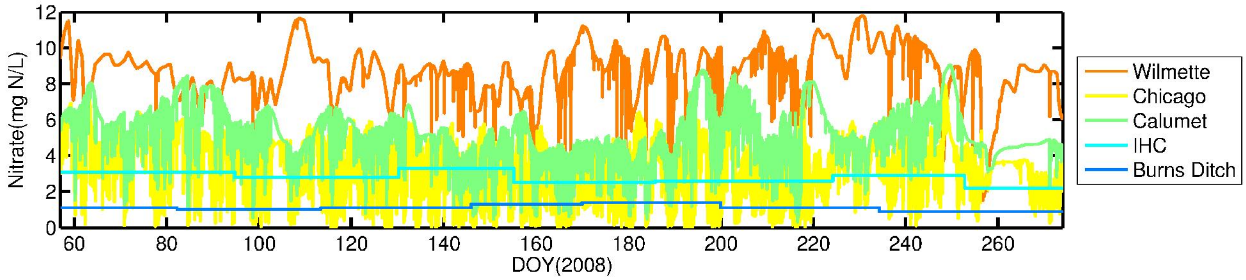


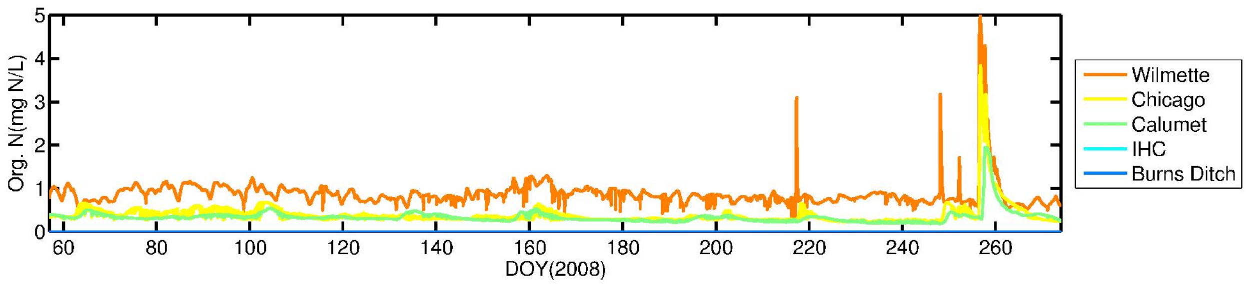









Nitrate(mg N/L)
0
2
4
6
8
10
12
60
80
100
120
140
160
180
200
220
240
260
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch


Org. N(mg N/L)
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3
4
5
60
80
100
120
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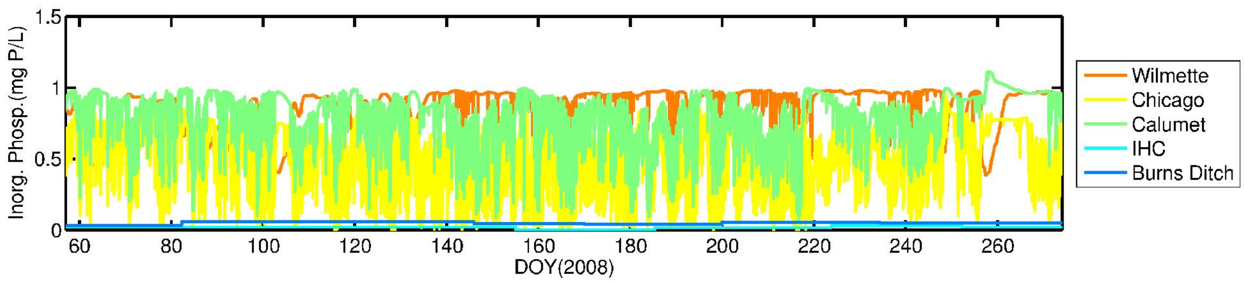
160
180
200
220
240
260
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch


Inorg. Phosp.(mg P/L)
0
0.5
1
1.5
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100
120
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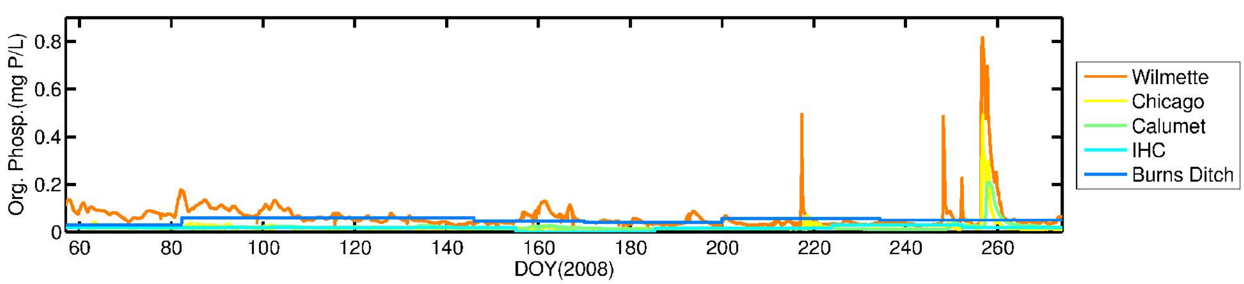
160
180
200
220
240
260
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch


Org. Phosp.(mg P/L)
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0.4
0.6
0.8
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180
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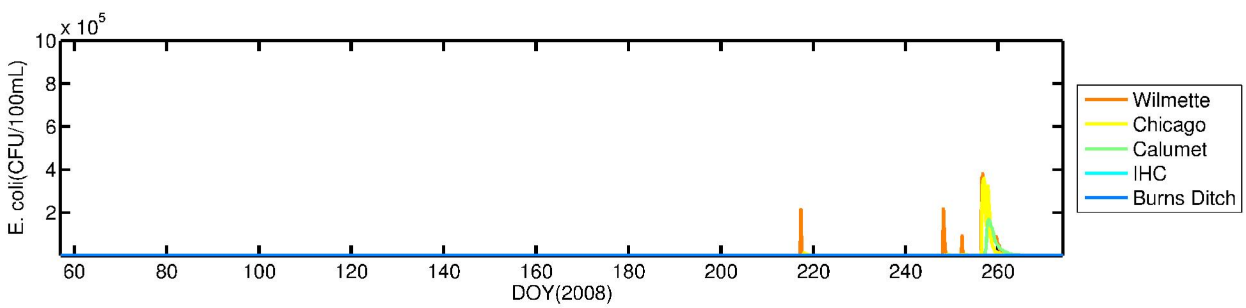
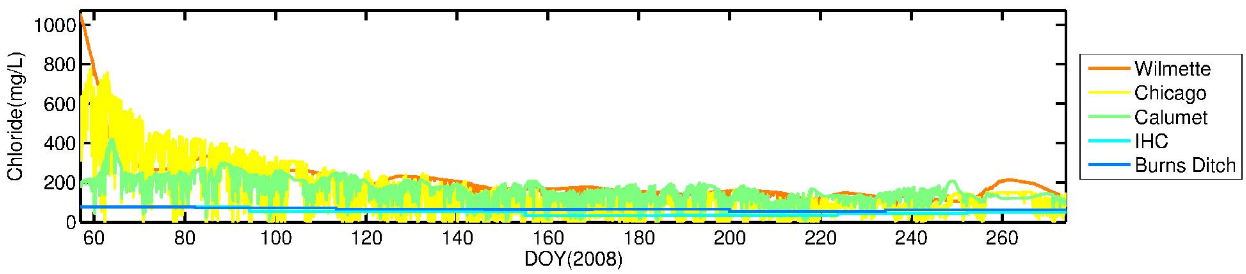
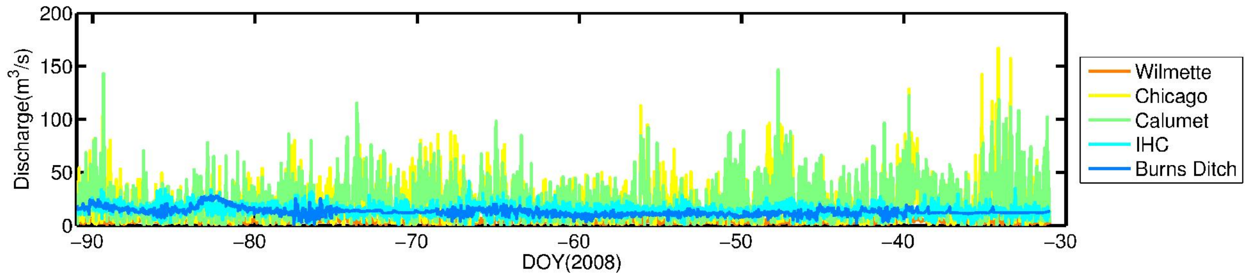
220
240
260
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

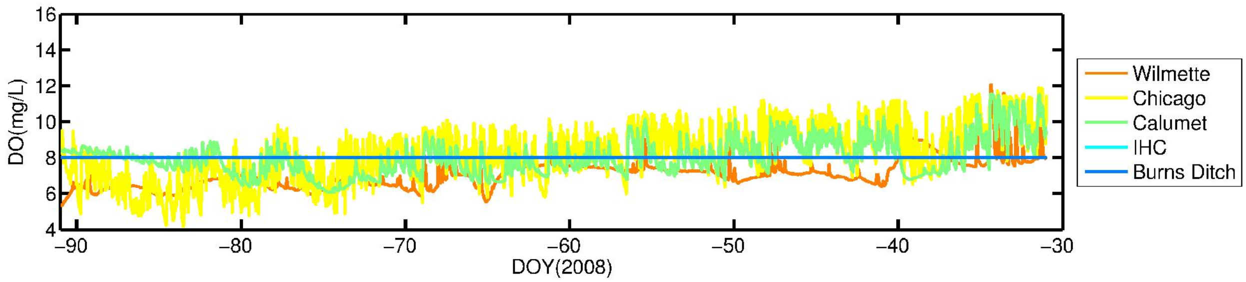

x 10^5
E. coli(CFU/100mL)
2
4
6
8
10
60
80
100
120
140
160
180
200
220
240
260
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

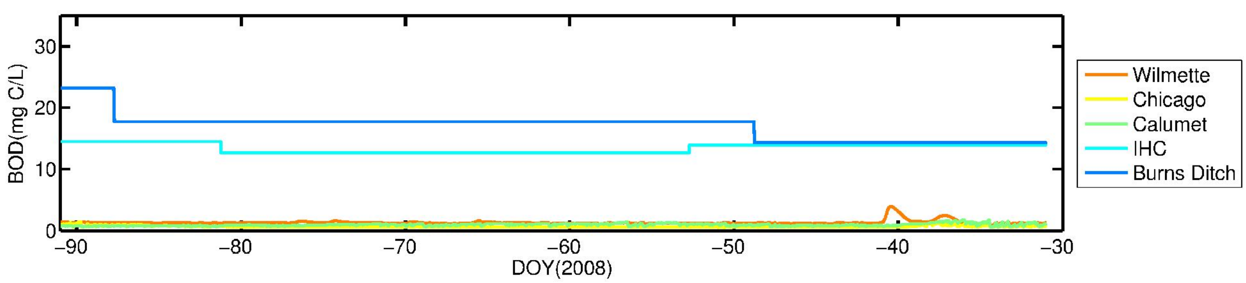


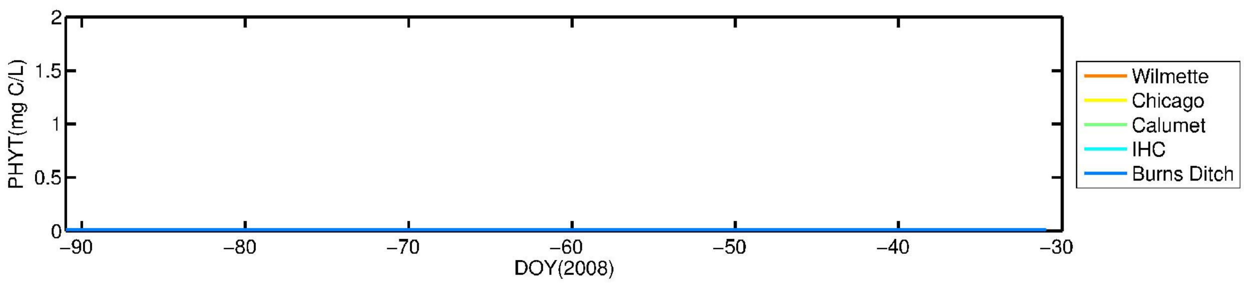
1000
800
600
400
200
0
Chloride(mg/L)
60
80
100
120
140
160
180
200
220
240
260
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

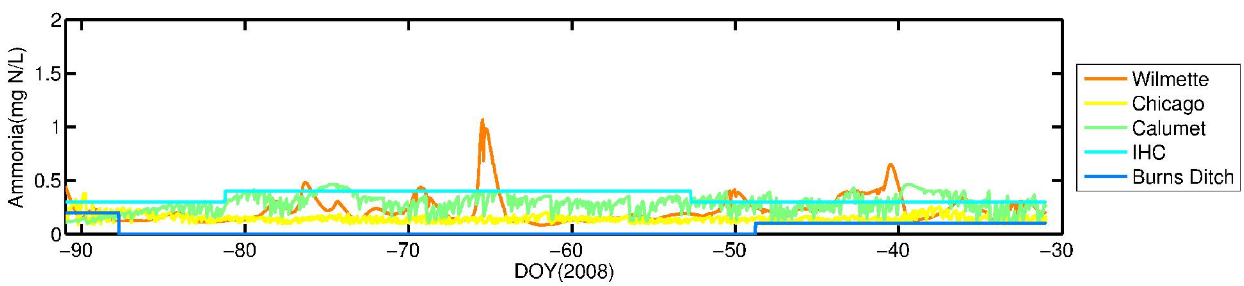
Scenario 3: Sept2007-November2007

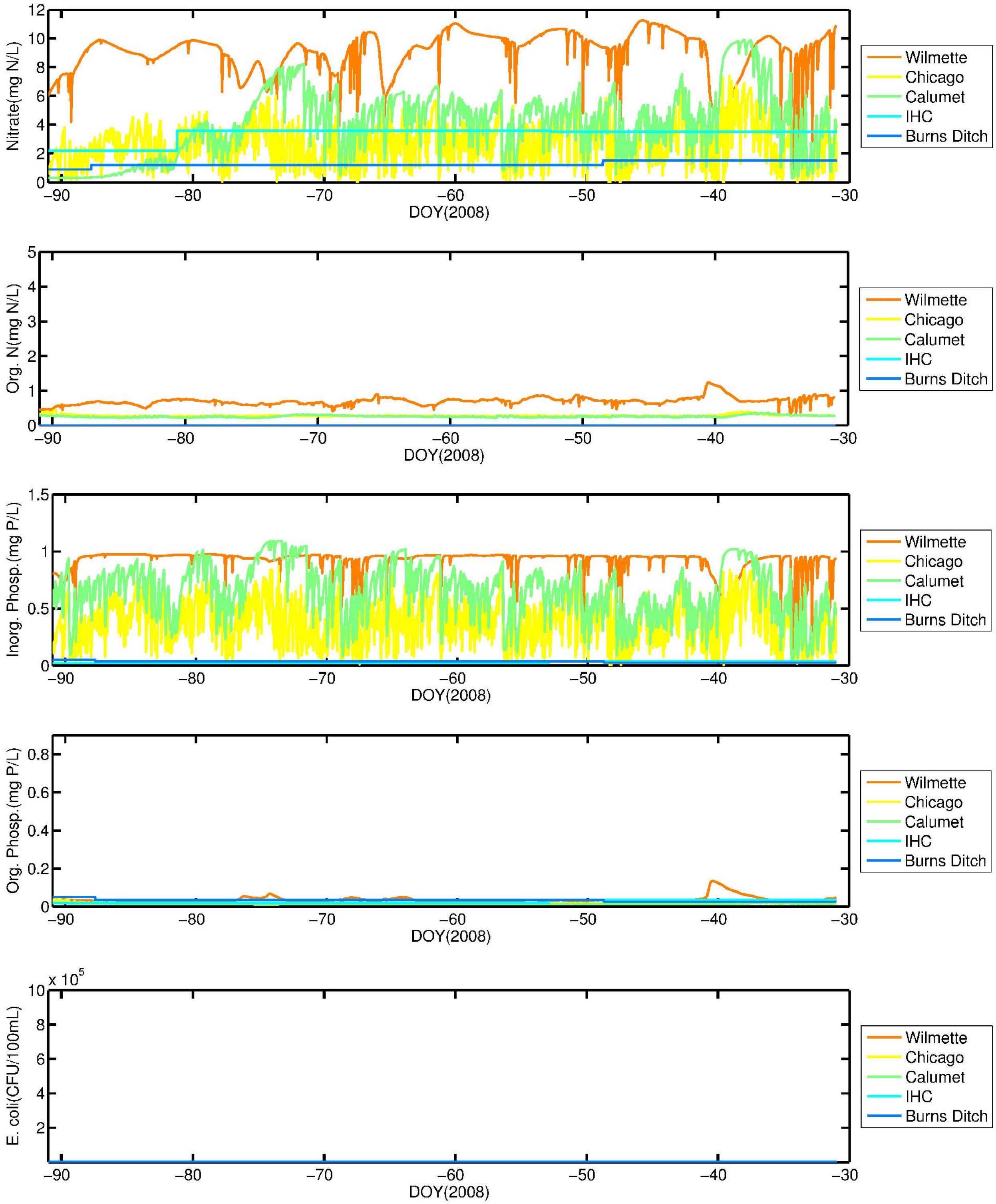


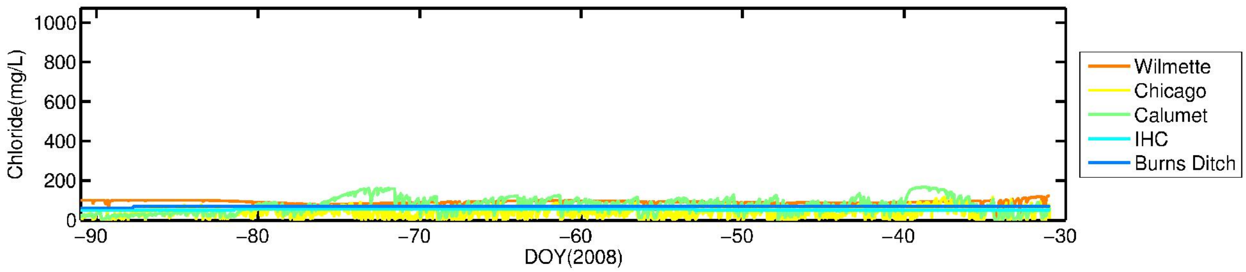






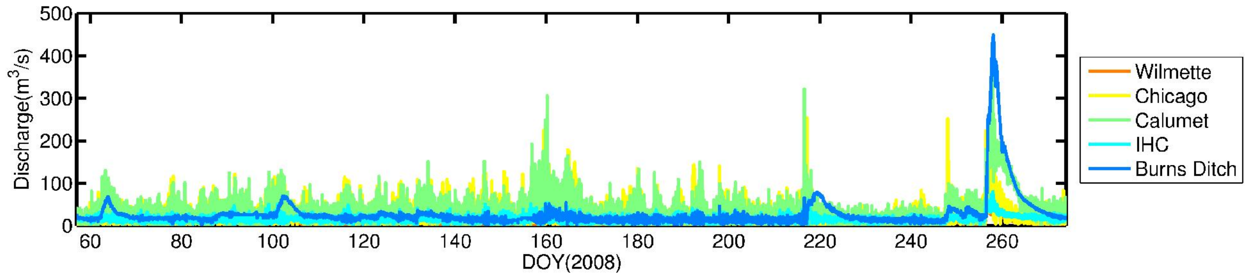


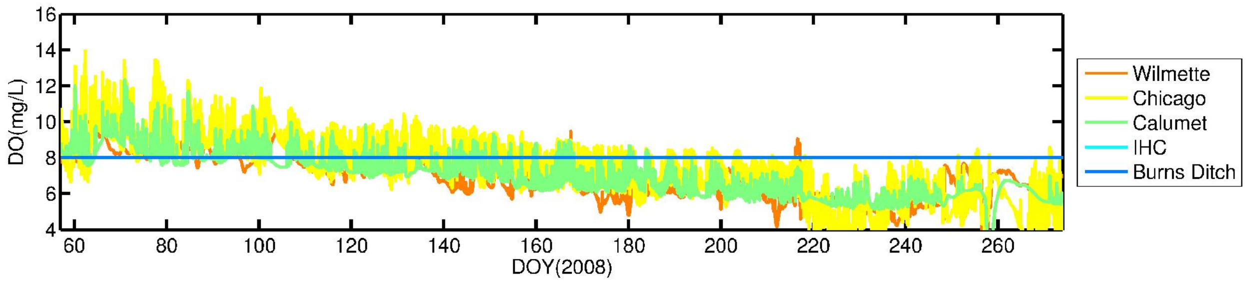

Nitrate(mg N/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch
Org. N(mg N/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch
Inorg. Phosp.(mg P/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch
Org. Phosp.(mg P/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch
x 10^5
E. coli(CFU/100mL)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

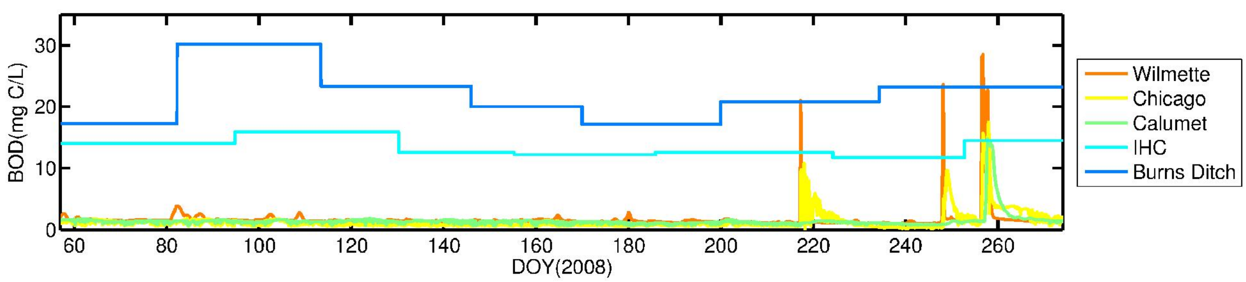


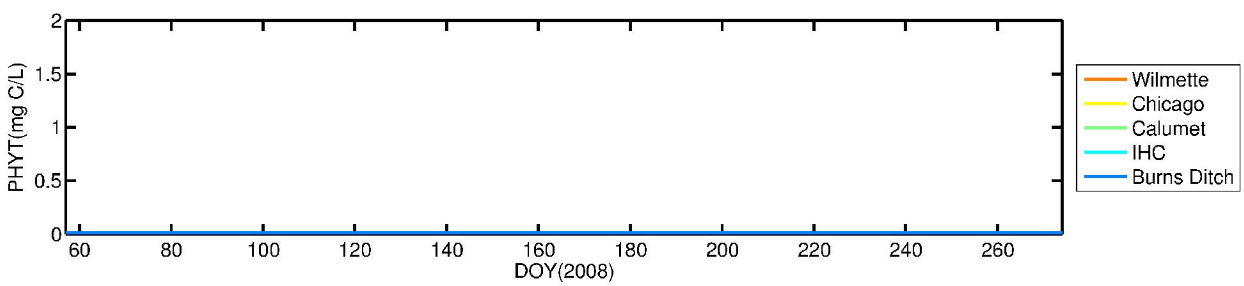
Chloride(mg/L)
1000
800
600
400
200
0
−90
−80
−70
−60
−50
−40
−30
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

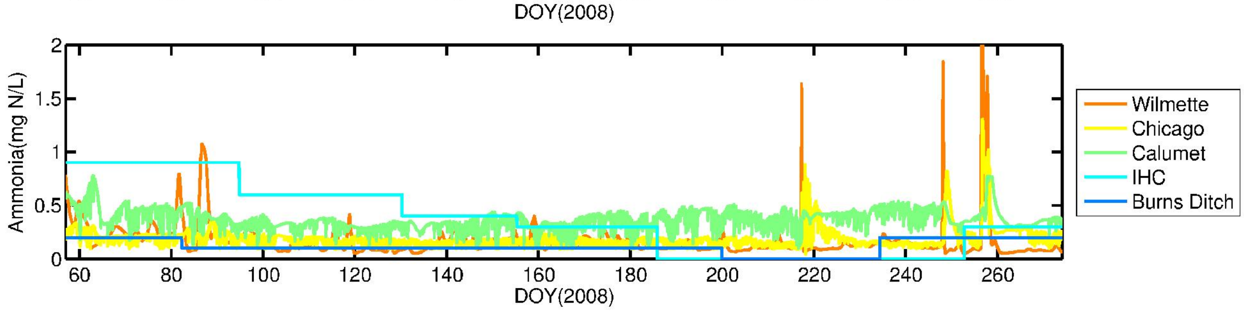
Scenario 3: March2008-September2008

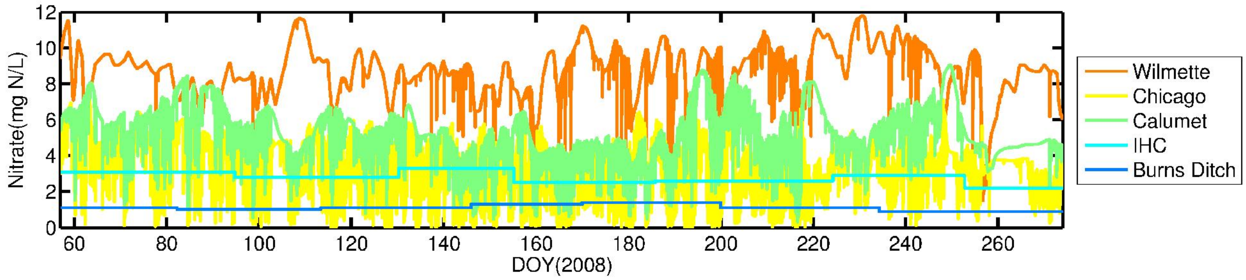


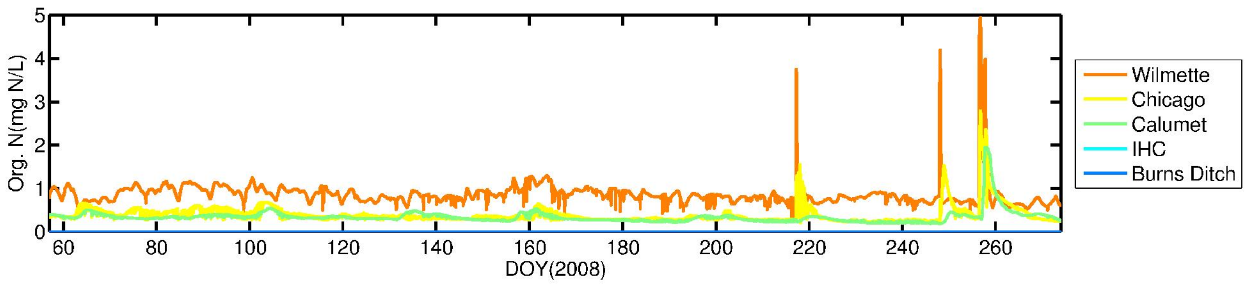


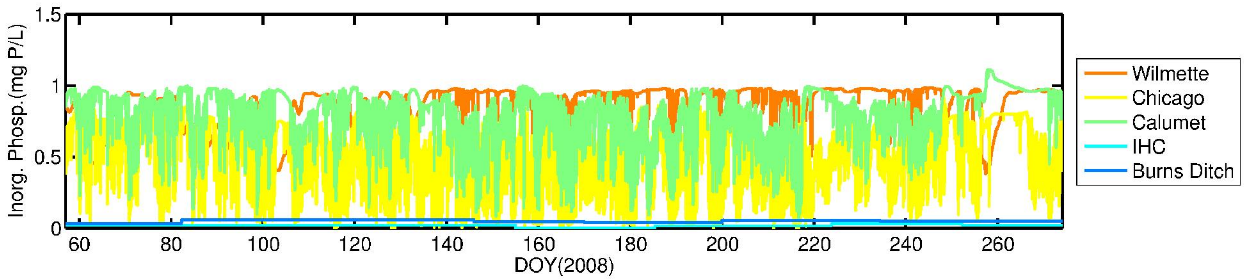







Nitrate(mg N/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch


Org. N(mg N/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch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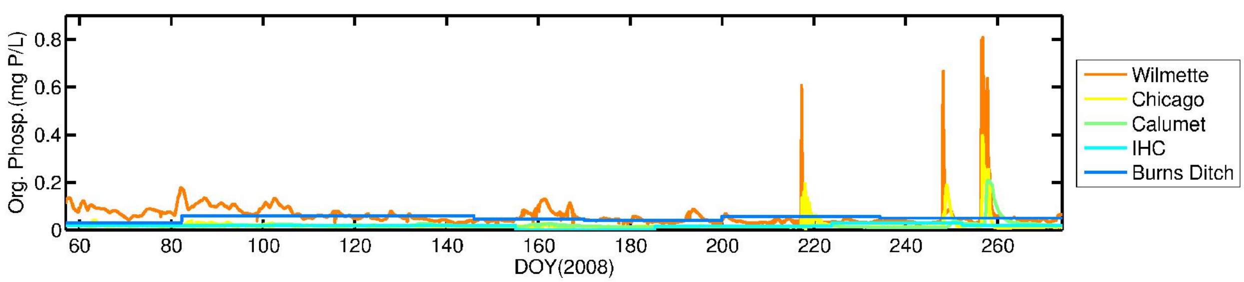
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch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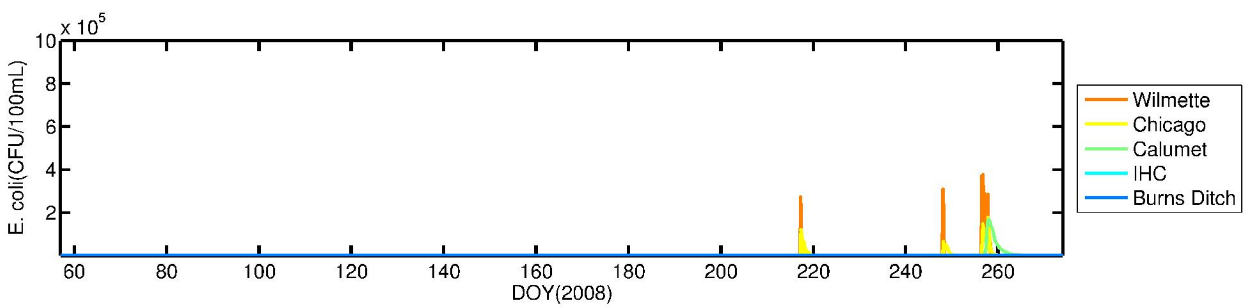
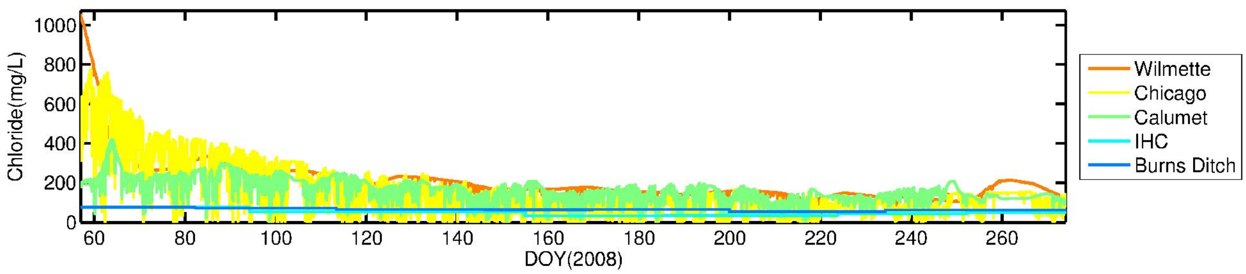
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch


x 10^5
E. coli(CFU/100mL)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch


Chloride(mg/L)
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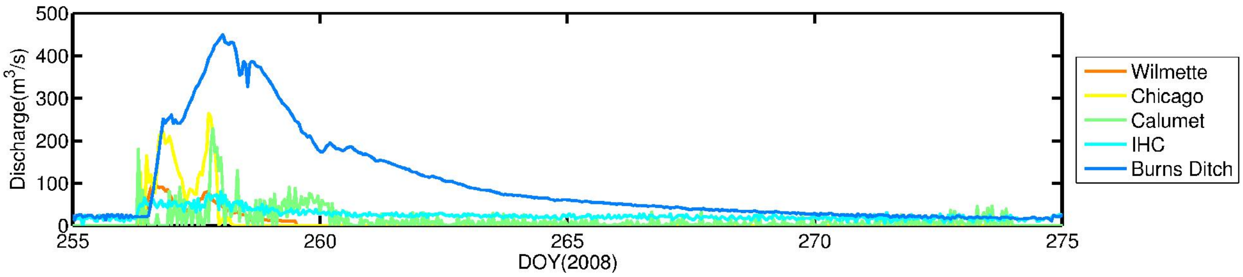
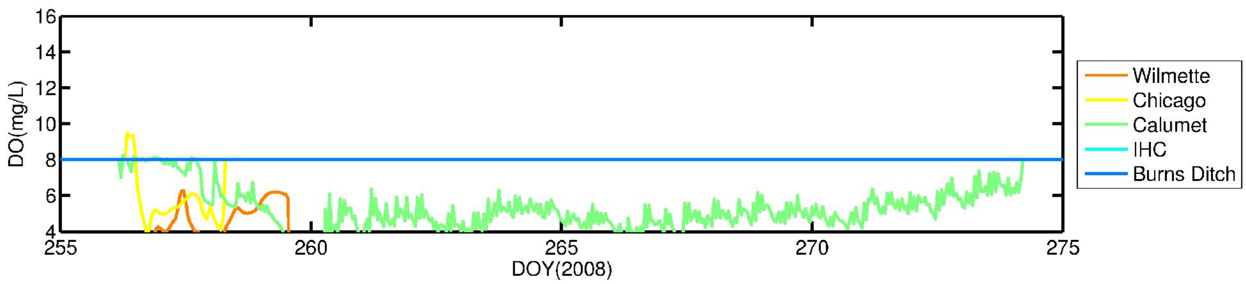
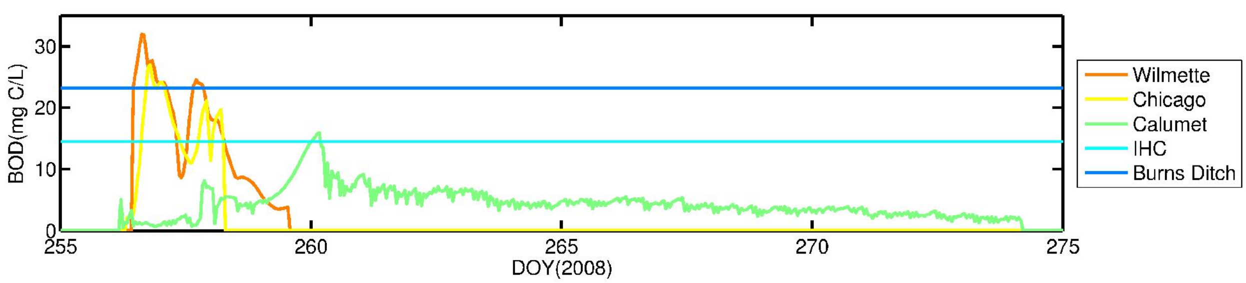
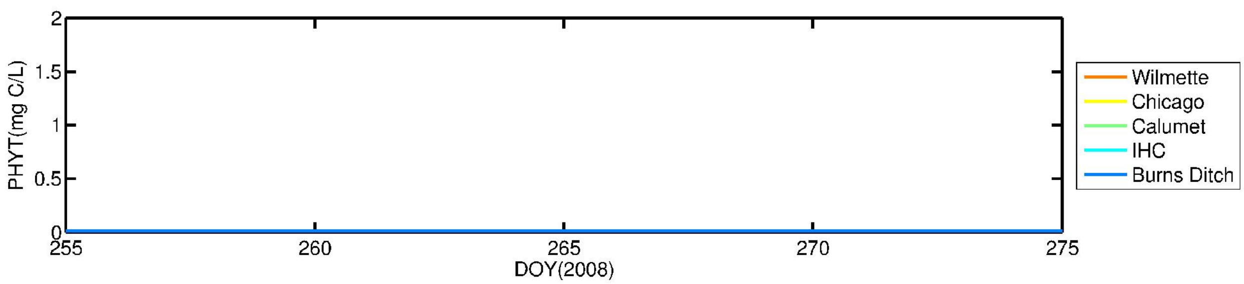
200
400
600
800
1000
60
80
100
120
140
160
180
200
220
240
260
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

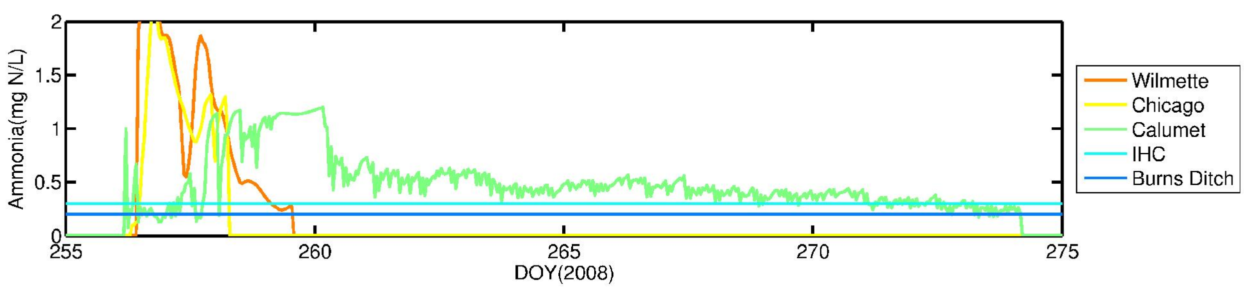
Scenario 4: September

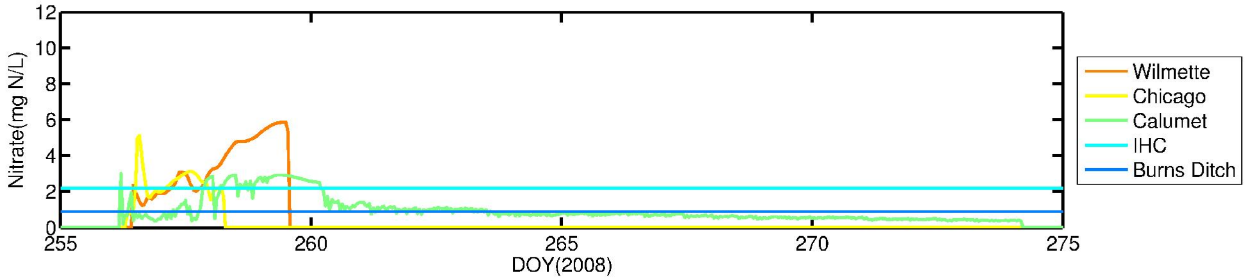


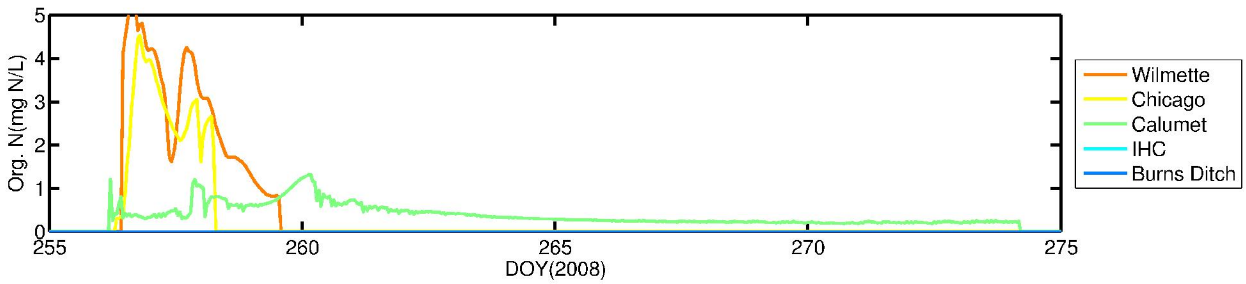


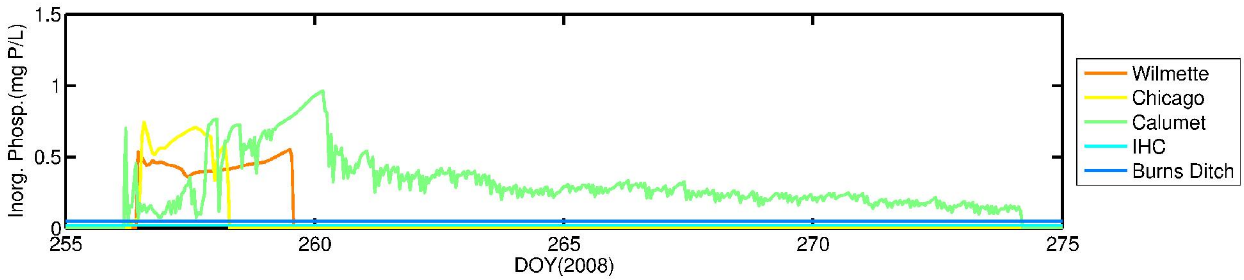


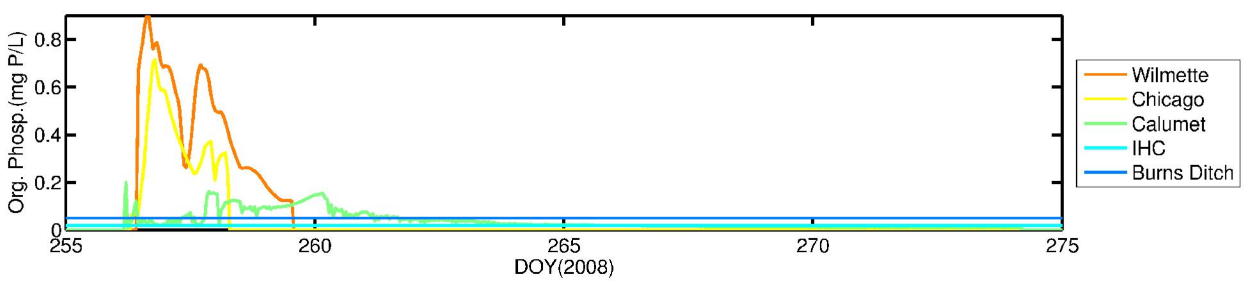





Nitrate(mg N/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch


Org. N(mg N/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch


Inorg. Phosp.(mg P/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch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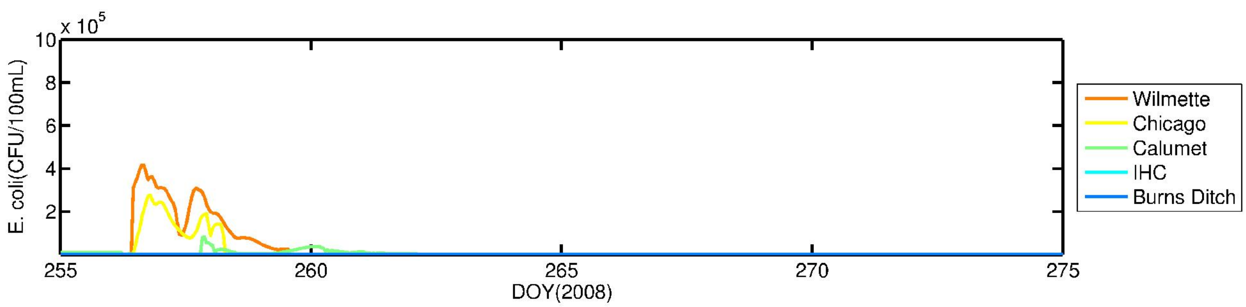
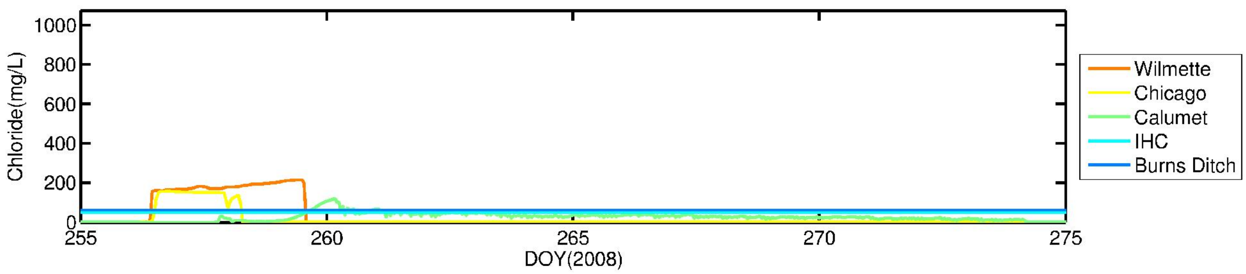
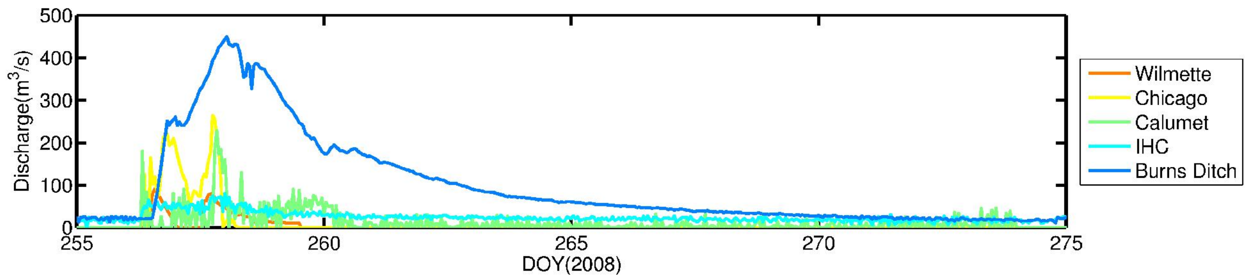
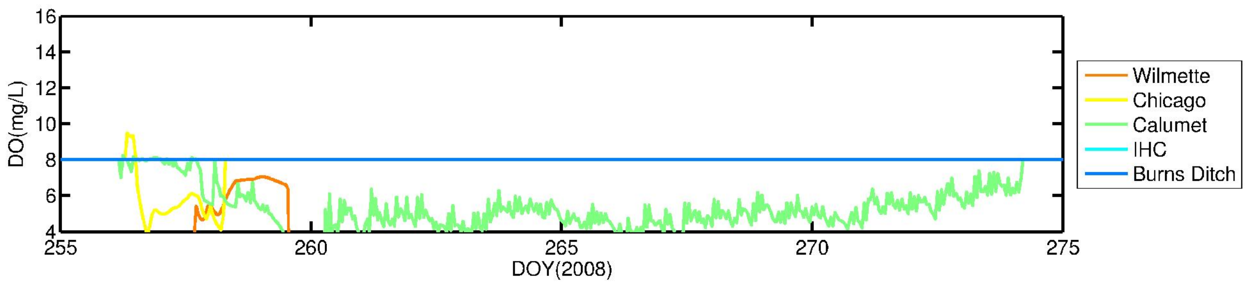
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

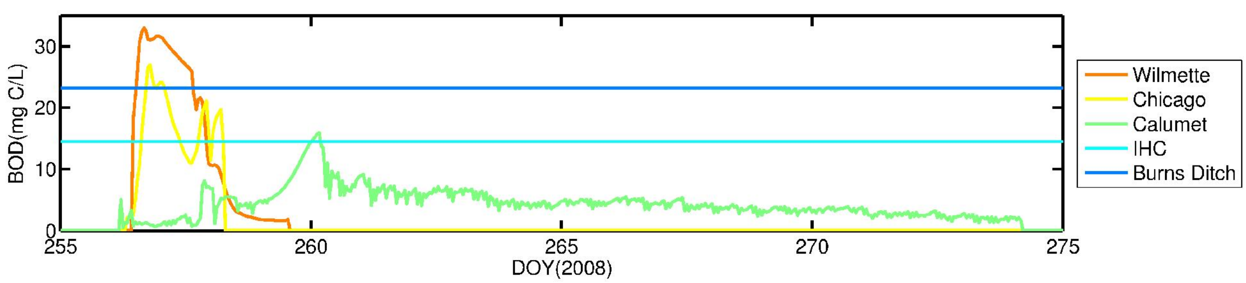

x 10^5
E. coli(CFU/100mL)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

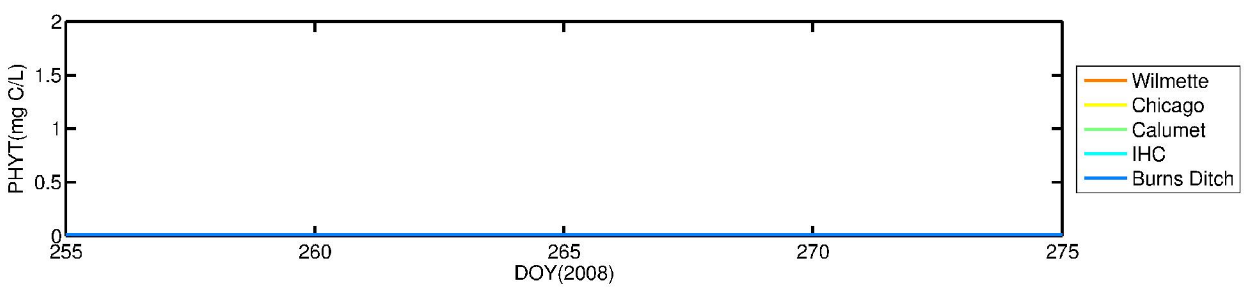

1000
800
600
400
200
0
Chloride(mg/L)
255
260
265
270
275
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

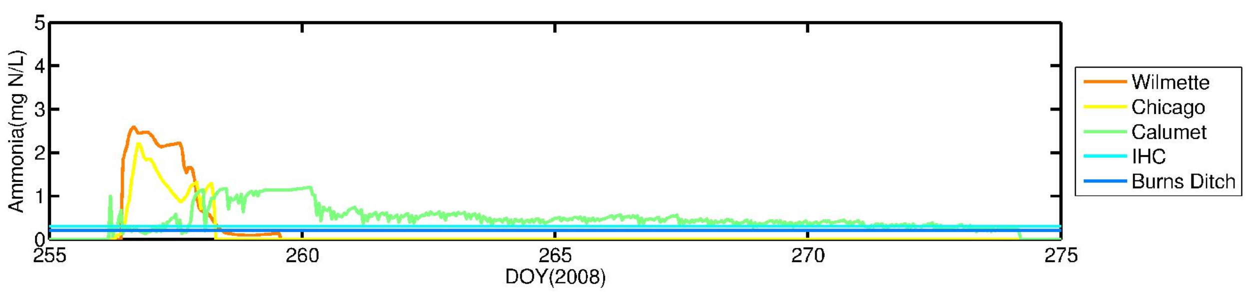
Scenario 5: September

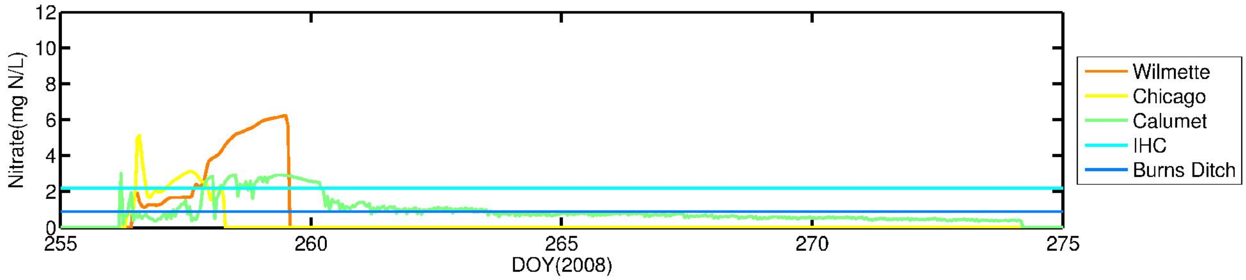


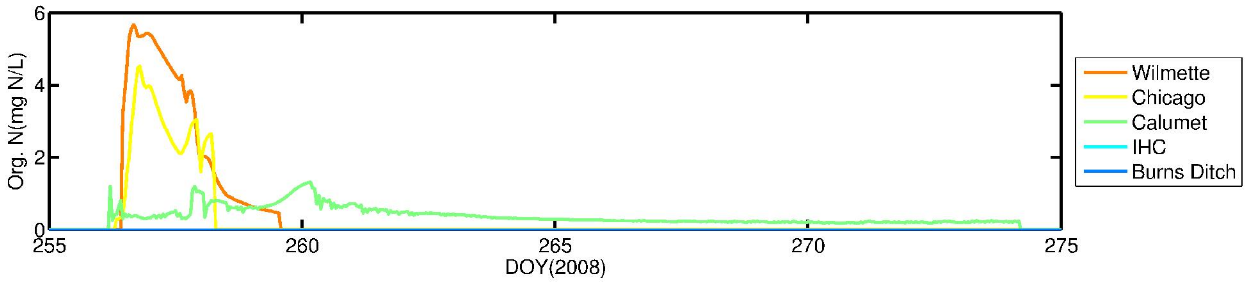


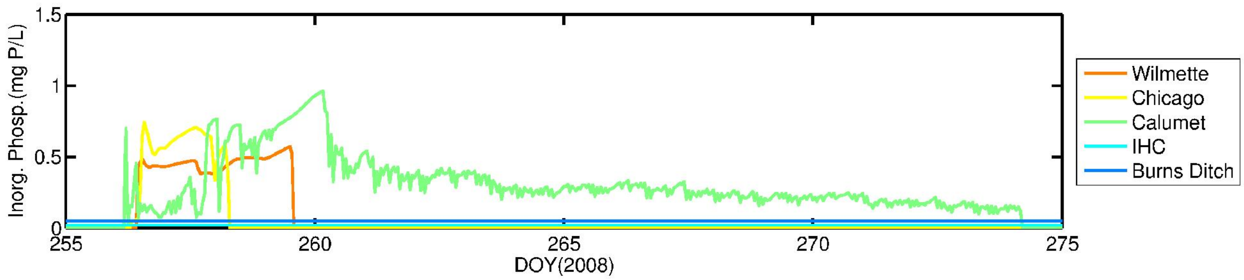


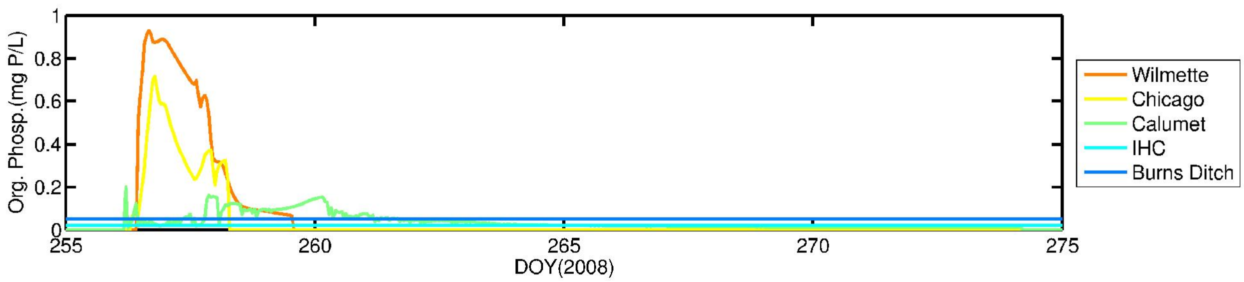


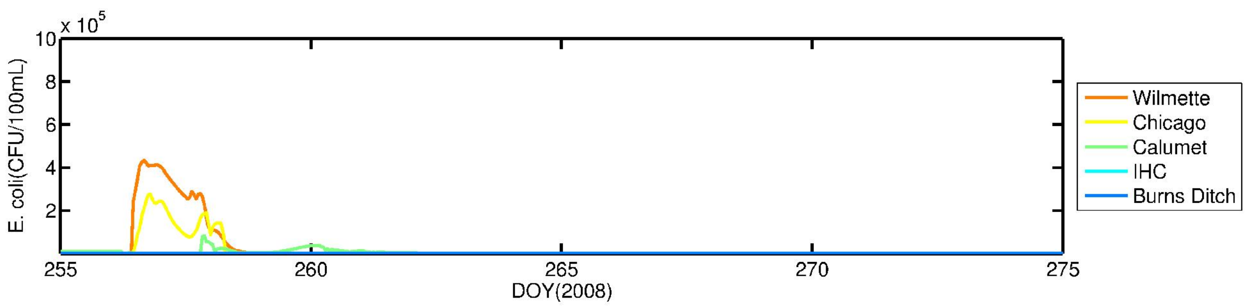


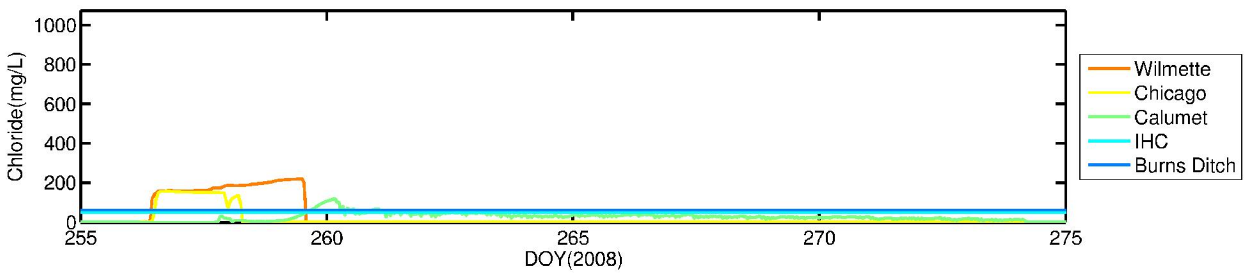

Nitrate(mg N/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch


Org. N(mg N/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch


Inorg. Phosp.(mg P/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch


Org. Phosp.(mg P/L)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch


x 10^5
E. coli(CFU/100mL)
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch



Chloride(mg/L)
1000
800
600
400
200
0
255
260
265
270
275
DOY(2008)
Wilmette
Chicago
Calumet
IHC
Burns Ditch

Appendix C

Table 1 Maximum, minimum and standard deviation of the of the vertically averaged water quality variables at major water intake locations (for Scenario 3) for 30 day period (Sept 1 - Sept 30)

Variable	Location.	Min.	Max.	Mean	Std. dev.
DO	Evanston	8.3466	10.503	8.752	0.51691
(mg/l)	Jardine(crib)	8.2082	9.7879	8.568	0.31144
	Jardine(shore)	6.6067	13.717	9.9869	1.7878
	South(crib)	7.9146	10.29	8.5942	0.47867
	South(shore)	8.1173	14.035	10.591	1.5848
	Hammond	7.994	14.249	10.154	1.3759
	Gary	7.3904	8.723	7.9808	0.30489
CBOD	Evanston	0.053343	1.0653	0.32583	0.29522
(mg C/l)	Jardine(crib)	0.090679	0.93867	0.30686	0.20438
	Jardine(shore)	0.13242	7.7814	1.3571	1.0079
	South(crib)	0.13596	1.261	0.40656	0.26144
	South(shore)	0.22573	3.1538	1.279	0.81185
	Hammond	0.32391	2.9639	1.22	0.62989
	Gary	0.051366	1.2652	0.33682	0.23244
Phytoplankton	Evanston	0.01602	0.68025	0.1604	0.16211
	Jardine(crib)	0.017239	0.53972	0.1351	0.11462
	Jardine(shore)	0.060292	1.5134	0.59557	0.45362
	South(crib)	0.0314	0.72694	0.16951	0.14725
	South(shore)	0.071253	1.5314	0.74215	0.42102
	Hammond	0.097121	1.6121	0.62889	0.3846
	Gary	0.00551	0.24791	0.058985	0.043718
Ammonia	Evanston	0.000277	0.029601	0.002112	0.003356
(mg N/l)	Jardine(crib)	0.000432	0.004474	0.001487	0.000773
	Jardine(shore)	0.000804	0.5404	0.021126	0.05578
	South(crib)	0.000682	0.005916	0.001711	0.001089
	South(shore)	0.001079	0.047672	0.005075	0.006716
	Hammond	0.001112	0.037551	0.004181	0.005095
	Gary	0.000172	0.004633	0.001212	0.000835
Nitrate	Evanston	0.002729	0.37905	0.042357	0.046515
(mg N/l)	Jardine(crib)	0.0032	0.17759	0.03013	0.026949
	Jardine(shore)	0.000262	2.4218	0.49847	0.49168
	South(crib)	0.002396	0.36367	0.041685	0.058092
	South(shore)	0.000146	2.5871	0.53085	0.75058
	Hammond	0.002555	1.7628	0.31231	0.38057
	Gary	0.004048	0.099188	0.029389	0.020797
Org. Nitrogen	Evanston	0.082719	0.2513	0.1353	0.04932
(mg N/l)	Jardine(crib)	0.096223	0.22649	0.12942	0.028403
	Jardine(shore)	0.10288	1.4191	0.33069	0.17892

	South(crib)	0.087356	0.28097	0.14068	0.042229
	South(shore)	0.13448	0.7193	0.29537	0.15824
	Hammond	0.11964	0.5558	0.23799	0.097368
	Gary	0.077409	0.15236	0.10742	0.022243
Phosphate(IP)	Evanston	0.008652	0.053683	0.021536	0.011631
(mg P/l)	Jardine(crib)	0.01055	0.073811	0.019821	0.009969
	Jardine(shore)	0.012758	0.47012	0.12919	0.092277
	South(crib)	0.009694	0.11024	0.022481	0.019291
	South(shore)	0.015251	0.6584	0.14454	0.17794
	Hammond	0.005246	0.36001	0.076771	0.092411
	Gary	0.007298	0.014838	0.010255	0.001869
Org. Phosphorous	Evanston	0.01129	0.032671	0.014307	0.003346
(mg P/l)	Jardine(crib)	0.011734	0.019322	0.013576	0.00155
	Jardine(shore)	0.011985	0.18152	0.024689	0.018088
	South(crib)	0.012314	0.022582	0.014118	0.002288
	South(shore)	0.01306	0.054409	0.022552	0.010778
	Hammond	0.013748	0.046085	0.019351	0.006348
	Gary	0.011381	0.014991	0.01284	0.000897
FIB	Evanston	1	1347.1	27.603	155.26
(CFU/100ml)	Jardine(crib)	1	23.887	2.3257	3.6983
	Jardine(shore)	1	38792	630.46	3577.3
	South(crib)	1	16.494	1.7242	2.518
	South(shore)	1	183.74	8.0284	26.992
	Hammond	1	536.36	31.818	106.03
	Gary	1	4.5224	1.1267	0.53189
Chloride	Evanston	14.453	26.236	17.423	2.6882
(mg/l)	Jardine(crib)	14.857	24.247	16.858	1.7942
	Jardine(shore)	15.263	102.22	36.668	17.218
	South(crib)	15.305	28.669	17.596	2.9142
	South(shore)	15.982	86.966	34.474	19.615
	Hammond	16.444	63.849	28.128	12.256
	Gary	14.598	18.577	15.963	0.90879

Table 2 Maximum, minimum and standard deviation of the of the vertically averaged water quality variables at major water intake locations (for the extreme event simulated in Scenario 5) for 30 day period (Sept 1 - Sept 30)

Variable	Location.	Min.	Max.	Mean	Std. dev.
DO	Evanston	8.1133	8.3457	8.2669	0.064302
(mg/l)	Jardine(crib)	8.1216	8.419	8.2681	0.060955
	Jardine(shore)	5.4783	8.7489	8.1554	0.54375
	South(crib)	8.1042	8.341	8.2669	0.066651
	South(shore)	7.1153	8.5824	8.299	0.22418
	Hammond	7.9246	9.3017	8.3778	0.24647
	Gary	7.8593	8.3707	8.1798	0.15729
CBOD	Evanston	0.002372	0.39583	0.092958	0.05834
(mg C/l)	Jardine(crib)	0.002373	0.23239	0.10527	0.062817
	Jardine(shore)	0.002371	14.232	0.69656	1.7389
	South(crib)	0.002373	0.38085	0.15809	0.11338
	South(shore)	0.002371	1.0265	0.2061	0.1863
	Hammond	0.002371	0.97997	0.31371	0.26668
	Gary	0.002373	0.92307	0.20004	0.15501
Phytoplankton	Evanston	0.025141	0.091908	0.044896	0.014732
	Jardine(crib)	0.028822	0.13251	0.047374	0.020407
	Jardine(shore)	0.022631	0.30702	0.096943	0.074416
	South(crib)	0.033354	0.13869	0.059445	0.030523
	South(shore)	0.035255	0.2159	0.079329	0.049184
	Hammond	0.036058	0.41074	0.10228	0.090059
	Gary	0.012416	0.18091	0.043664	0.026643
Ammonia	Evanston	2.43E-05	0.021925	0.000976	0.001877
(mg N/l)	Jardine(crib)	2.43E-05	0.00504	0.001089	0.001078
	Jardine(shore)	2.43E-05	1.0983	0.034349	0.13095
	South(crib)	2.43E-05	0.010663	0.001603	0.002151
	South(shore)	2.43E-05	0.050035	0.003431	0.007471
	Hammond	2.43E-05	0.030112	0.002424	0.003894
	Gary	2.43E-05	0.003489	0.001004	0.000758
Nitrate	Evanston	0.012492	0.10069	0.024658	0.011364
(mg N/l)	Jardine(crib)	0.009553	0.049393	0.023891	0.00831
	Jardine(shore)	0.002696	1.5256	0.1275	0.22414
	South(crib)	0.006085	0.080999	0.034046	0.017174
	South(shore)	0.002191	0.52805	0.061144	0.086435
	Hammond	0.00177	0.27056	0.070635	0.067251
	Gary	0.02134	0.088	0.037684	0.014346
Org. Nitrogen	Evanston	0.080031	0.15299	0.10118	0.018489
(mg N/l)	Jardine(crib)	0.080031	0.12999	0.10059	0.015926
	Jardine(shore)	0.080031	2.5225	0.23415	0.30586
	South(crib)	0.080031	0.15106	0.10211	0.019179

	South(shore)	0.080031	0.25449	0.11557	0.0376
	Hammond	0.080031	0.16208	0.10121	0.021492
	Gary	0.080031	0.12057	0.090551	0.007088
Phosphate(IP)	Evanston	0.006263	0.013853	0.00799	0.001658
(mg P/l)	Jardine(crib)	0.006449	0.014895	0.008199	0.001822
	Jardine(shore)	0.006114	0.36456	0.030412	0.047631
	South(crib)	0.006114	0.021823	0.008899	0.003871
	South(shore)	0.00566	0.12317	0.015893	0.019932
	Hammond	0.004596	0.059158	0.009143	0.00781
	Gary	0.00501	0.008279	0.006687	0.000476
Org. Phosphorous	Evanston	0.010002	0.020792	0.011995	0.002175
(mg P/l)	Jardine(crib)	0.010002	0.016652	0.011855	0.00172
	Jardine(shore)	0.010002	0.38133	0.030127	0.046069
	South(crib)	0.010002	0.018815	0.012118	0.002269
	South(shore)	0.010002	0.030894	0.013484	0.004421
	Hammond	0.010002	0.01991	0.011894	0.001854
	Gary	0.010002	0.013183	0.010988	0.000716
FIB	Evanston	1	1425.3	17.351	116.49
(CFU/100ml)	Jardine(crib)	1	85.457	5.8543	14.565
	Jardine(shore)	1	95799	1728.8	9847.3
	South(crib)	1	121.26	6.7236	19.162
	South(shore)	1	79.198	4.2513	11.922
	Hammond	1	42.243	2.456	5.5897
	Gary	1	4.4733	1.266	0.54887
Chloride	Evanston	13.969	16.918	14.502	0.62395
(mg/l)	Jardine(crib)	13.998	15.531	14.381	0.44081
	Jardine(shore)	13.775	102.98	19.668	11.486
	South(crib)	13.999	16.314	14.607	0.64265
	South(shore)	13.999	20.769	15.091	1.451
	Hammond	13.999	17.686	15.078	1.1377
	Gary	14	16.69	14.565	0.56092

Table 3: Water quality benchmarks

Variable	Benchmark
Total Phosphorous	0.007 mg/L
Chloride	12 mg/L
DO	7.2 mg/L
Nitrate	10 mg/L
Fecal Coliform/ *E. coli*	20 CFU/100mL

Natural Resources Integrated Information System

Basic Information

Title:	Natural Resources Integrated Information System
Project Number:	2014MI225B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	8
Research Category:	Water Quality
Focus Category:	Management and Planning, Water Quality, Water Quantity
Descriptors:	None
Principal Investigators:	Jon Bartholic

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1. Asher, A. and M. Thomas. Mid-Michigan Health Impact Assessment Tool. 2014. Michigan Power to Thrive Half-Day Summit on Health in All Policies. Michigan Public Health Institute Annual Summit in Lansing, MI.
2. Asher, A., J. Piwarski, and M. Thomas. Mid-Michigan Health Impact Assessment Tool. 2014. Power of We Consortium in Lansing, MI.
3. Asher, A. 2014. Developing an Ecological Scorecard for Great Lakes Communities. Extension Beyond Borders Conference: Strengthening Networks for Water Resource Management. October 1, 2014.
4. Asher, A. 2014. Connecting Communities: Sharing Tools and Technologies. Great Lakes Restoration Conference. September 10, 2014. Grand Rapids, MI.
5. Bartholic, J. 2014. Opportunities for Strengthening Regional Partnerships I. Extension Beyond Borders Conference: Strengthening Networks for Water Resource Management. October 2, 2014. Minneapolis, MN.
6. Piwarski, J. and Young, L. 2014. Online Agricultural Mapping Tools for your Classroom and in the Field. Michigan Association of Agriscience Teachers Fall PDI Conference. October 17 in Lansing, MI.
7. Wolfson, L., L. Young, and K. Freestone. 2014. Great Lakes Clean Communities Network (poster). North Central Region Water Network Conference. October 1-2, 2014. Minneapolis, MN. Funding agency: Great Lakes Protection Fund.
8. Young, L. and S. Seedang. 2014. A User Assessment of Decision Support Tools for Addressing Nonpoint Source Pollution in the Saginaw Basin Watershed: Environmental Learning Using Computer Interactive Decisions (ELUCID) and the Great Lakes Watershed Management System (GLWMS). Soil Water Conservation Society International Annual Conference, Lombard, IL.
9. Young, L. 2014. Lessons Learned: Empowering Local Organizations through Information Technologies. Saginaw Bay Watershed Conference, University Center, MI.
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14. ELUCID Demonstration for EPA GLRI Regional Meeting. April 8, 2014. East Lansing, MI.
15. ELUCID Demonstration for NRCS - Great Lakes Region (webinar). May 15, 2014. East Lansing, MI.
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18. Bartholic, J. 2014. Water and its Economic Advantage for Michigan's Food and Agriculture System. Michigan Commission of Agriculture and Rural Development. September 17, 2014.
19. Asher, A., J. Piwarski, J., and M. Thomas. 2014. Mid-Michigan Health Impact Assessment Tool. The Land Use and Health Resource Team Action Team Workshop in East Lansing, MI.
20. Wolfson, L., L. Young, K. Freestone. 2014. Great Lakes Clean Communities Network (poster). Extension Beyond Borders: Strengthening Networks for More Effective Water Resource Management. North Central Region Water Network Conference. October 1-2. Minneapolis, MN.
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26. Young, L. 2014. ELUCID Training Manual and Tutorials, in support of the Flint River Nutrient Reduction: Focusing Action Project, funded by the Great Lakes Restoration Initiative (GLRI). (GLRI--what was prepared for trainings/posted on website)
27. Young, L. and S. Seedang. 2014. A User Assessment of Decision Support Tools for Addressing Nonpoint Source Pollution in the Saginaw Basin Watershed: Environmental Learning Using Computer Interactive Decisions (ELUCID) and the Great Lakes Watershed Management System (GLWMS). Soil Water Conservation Society International Annual Conference, July 29, 2014, Lombard, IL.
28. Young, L. and J. Asher. 2014. Demonstration of the Great Lakes Watershed Management System, part of the Watershed Scale Conservation: How much is Enough? Symposium. Soil Water Conservation Society International Annual Conference, 29 July 29, Lombard, IL.
29. Young, L. 2014. Approaches to Technology Transfer: Experiences from IWR. International Short Course in Water Management. September 12, 2014. East Lansing, MI.
30. Young, L. 2014. ELUCID Demonstration for Tri-County Regional Planning Commission. February 12, 2014. Lansing, MI.
31. Wolfson, Lois, Jason Piwarski, Laura Young. 2014. Presented Go Green Help Keep our Water Clean at MSU ScienceFest on 4 April in East Lansing, MI.
32. Young, L. 2014. ELUCID Demonstration for EPA GLRI Regional Meeting. April 8, 2014. East Lansing, MI. Supported by a grant from the Great Lakes Restoration Initiative.
33. Young, L., J. Piwarski, and Y. Shi. 2014. ELUCID Decision Support System and Field-Scale Analysis Training. May 7 and May 14, 2014. Flint, MI. Supported by a grant from the Great Lakes Restoration Initiative.
34. Young, L. 2014. Online Mapping Tools for Identifying Problem Areas in the Field Using Your iPad (webinar). MSU Extension SERV. 29 May. Supported by a grant from the Great Lakes Restoration Initiative.

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36. C. Lowry, L. Young and J. Asher. 2014. CrowdHydrology. Water Use Advisory Council Inland Lakes Work Group. Lansing, MI. Funding agency: United States Geological Survey 104b. October 13, 2014.
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49. Latimore, J. A., and L.G. Wolfson. 2014. Developing Local Leaders for Aquatic Ecosystem Conservation, Joint Aquatic Sciences Meeting, Joint Aquatic Science Meeting, Portland, OR, May.
50. Young, L., J. Piwarski, and Y. Shi. 2014. ELUCID Decision Support System and Field-Scale Analysis Training. Flint, MI. Funding agency: Environmental Protection Agency. May 7 and May 14.
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(GLRI--what was prepared for trainings/posted on website)

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54. Young, L. and S. Seedang. 2014. A User Assessment of Decision Support Tools for Addressing Nonpoint Source Pollution in the Saginaw Basin Watershed: Environmental Learning Using Computer Interactive Decisions (ELUCID) and the Great Lakes Watershed Management System (GLWMS). Soil Water Conservation Society International Annual Conference, July 29, 2014, Lombard, IL.
55. Young, L. and J. Asher. 2014. Demonstration of the Great Lakes Watershed Management System, part of the Watershed Scale Conservation: How much is Enough? Symposium. Soil Water Conservation Society International Annual Conference, 29 July 29, Lombard, IL.
56. Young, L. 2014. Approaches to Technology Transfer: Experiences from IWR. International Short Course in Water Management. September 12, 2014. East Lansing, MI.
57. Young, L. 2014. ELUCID Demonstration for Tri-County Regional Planning Commission. February 12, 2014. Lansing, MI.
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59. Young, L. 2014. ELUCID Demonstration for EPA GLRI Regional Meeting. April 8, 2014. East Lansing, MI. Supported by a grant from the Great Lakes Restoration Initiative.
60. Young, L., J. Piwarski, and Y. Shi. 2014. ELUCID Decision Support System and Field-Scale Analysis Training. May 7 and May 14, 2014. Flint, MI. Supported by a grant from the Great Lakes Restoration Initiative.
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64. Young, L. 2014. Lessons Learned: Empowering Local Organizations through Information Technologies. Saginaw Bay Watershed Conference, June 12, 2014, University Center, MI.
65. Young, L. 2014. ELUCID Teacher Training for Flint River GREEN Program. February 27, 2014. Flint, MI. Supported by a grant from the Great Lakes Restoration Initiative.

Title: Natural Resources Integrated Information System
Project Number: 2013MI220B
Start: 03/01/14 (actual)
End: 02/28/15 (actual)
Funding Source: USGS 104(B)
Congressional District: eighth
Research Category: Water Quality
Focus Categories: Management and Planning, Water Quality, Water Use
Descriptors: Management and Planning, Water Quality, Water Use
Primary PI: Jon F. Bartholic, Director, Institute of Water Research, Michigan State University, East Lansing, MI 48823, bartholi@msu.edu
Project Class: Research

Problem and Research Objectives

Nature and Importance to the Problem and Relevance to the Mission

Water is replacing oil as one of the single most important resources upon which policy and, in fact, human existence in many portions of the globe will depend. Political power, economics, and civilization's development will be critically impacted by our ability to sustainably manage and optimally utilize the planet's water resources. Because of the United States' relative advantage from a water resource standpoint, this country's role will be increasingly significant in food production and industrial production requiring significant quantities of water, and in developing sustainable approaches to maintain waters' ecological services. Specifically, the Great Lakes region will have tremendous opportunities to capitalize in numerous ways on the potential of its vast water resources. But, water resources management always occurs in a social context involving multiple stakeholders. Stakeholders can have radically different perceptions of the problems and potential trade-offs associated with finding solutions because of dynamic social, economic, and political factors as well as biophysical complexities of water resource issues. This complex nature of water resource management and other related issues, such as global climate change and health care, is often referred to in the scientific community as "wicked." Research on wicked-type problems suggests that a comprehensive knowledge system sustained by a boundary organization is essential. Boundary organizations act as intermediaries between science and policy because they fulfill or possess (see Figure 1): 1) specialized roles within the organization for managing the boundary; 2) clear lines of responsibility and accountability to distinct social arenas on opposite sides of the boundary; and 3) a forum in which information can be co-created by research and interested parties. Since its very beginning and long history of existence, the Institute of Water Research (IWR) has been functioning as a boundary organization to tackle wicked water resource management issues. Through a history of extensive knowledge generation, engagement and facilitation, and working experience with local, state, and basin-wide organizations, IWR has a solid base of success to build upon in creating innovative knowledge systems for sustainable management of water resources.

<u>Previous Work and Present Outlook</u>

- Broad Guidance: Impact Support
- Research Projects
- Spatial Decision Support Systems (SDSS)
- Building a Great Lakes Basin-Wide IT/Decision Support/Networking System

Broad Guidance: Impact Support

<u>Water Use Advisory Council Support</u>

The Michigan Department of Environmental Quality (MDEQ) convened the Water Use Advisory Council, made up of roughly 30 members, for a two-year appointment in early 2013 to advise MDEQ Director Dan Wyant on Michigan’s Water Use Program. The Council concluded its work in December of 2014. A final report consisting of 69 recommendations was submitted to Director Wyant. Diverse interests were represented on the Council, including those from government, non-profit organizations, and those representing agricultural, industrial, commercial, or environmental interests. The MSU-IWR had ex-officio membership on the Council and Frank Ruswick served as a co-chair of the Water Conservation and Use Efficiency work group.

Through an MOU with the MDEQ, the MSU-IWR also provided administrative support to the Council. The IWR was responsible for preparing meeting summaries and coordinating all meeting logistics. In addition, the IWR compiled the Council’s final report, which included a recommendations matrix outlining all 69 recommendations and their respective implementation considerations. The final report, meeting summaries and other materials are available at www.michigan.gov/wateruse. Being intimately involved with Council activities allowed the IWR to understand emerging needs relating to water use within the state and directly align certain project activities with major issues identified through the Council. For example, a major focus of the USDA-NIFA funded project at the IWR is the development of decision support tools to assist water users committees outlined in the legislation that dictates requirements of MDEQ’s Water Use Program.

<u>White paper per request the Michigan Office of the Great Lakes for inclusion in the Michigan Water Strategy: The Water Cycle: Wise Use of Michigan's Water Cycle – Resources - Prepared March 2014</u>

The I IWR prepared a white paper for inclusion in the Michigan Water Strategy regarding wise use of Michigan's water cycle and resources. A main goal covered in the paper emphasized that Michigan's water resources need to be maintained with a goal that optimizes community and human health, and natural, recreational, economic, and cultural uses and values. Addressing this goal requires a water resource perspective that begins with an overview and understanding of Michigan's water cycle and how its components interact.

The White Paper examined Michigan's Water Cycle: The hydrologic or water cycle is frequently divided into five major components (primary elements) - rainfall (precipitation), infiltration, evapotranspiration, runoff, and storage/groundwater. The values of these components for

Michigan are relatively robust in size compared with more arid regions; e.g. the Western U.S. The paper highlighted the challenge of scale since there is great and dynamic variability in these components across Michigan. For example, in some areas additional impervious surfaces may lead to increased runoff, less infiltration, and subsequently, greater flooding downstream. In other areas infiltration may provide inadequate recharge (storage) to keep up with withdrawals via wells from groundwater (storage) for continued urban and agricultural uses. Thus, it is critical in a Water Strategy to be well-informed about the "big" picture (basin or statewide) along with more detailed knowledge at the local watershed level. For instance, Michigan's present water withdrawal registration policy system is divided into approximately 5300 differentiated stream reaches/sub-watersheds. Additionally, since water moves vertically from the surface to groundwater but also moves laterally both above and below ground, the vertical/horizontal flux characteristics need to be included in any local water balance investigation. These broad factors along with others are required to assure that, *"water infrastructure is well-designed and maintained to support recreational, economic, and cultural uses and values."*

White Paper per request of the Michigan Office of the Great Lakes for inclusion in the Michigan Water Strategy: The Status and Future of Water Conservation in Michigan – Prepared February 2015

A conservation perspective that marries economic drivers and a desire and obligation for care and stewardship should be the foundation for Michigan's water management policy. As the fundamental basis for holding on to water in the Great Lakes, it would place Michigan and the region in a strong position to demand conservation performance by those who may covet the water riches of the Great Lakes. This White Paper examined Michigan's approach to water conservation and stressed that it need not be based on the exigencies of immediate or widespread scarcity. It called for the development of an integrated system of water conservation driven by deep respect and care for water as the basis of life.

Michigan Natural Resources Working Group

Background

The Michigan Natural Resources Working Group (NRWG ~ initiated and facilitated by MSU-IWR) is a partnership of federal, state and local agencies and organizations with an interest in conserving Michigan's natural resources. Partners include the Great Lakes Commission, Michigan Department of Agriculture and Rural Development, Michigan Department of Environmental Quality, Michigan Farm Bureau, The Nature Conservancy, US Geological Survey, USDA Natural Resources Conservation Service, US Fish and Wildlife Service, Shiawassee Conservation District, Lenawee Conservation District and Michigan State University (Institute of Water Research; Department of Sociology; Michigan State Extension; Department of Community Sustainability; Land Policy Institute).

The partners first met in November 2011 and have since been meeting regularly. The goal of the initial meeting was for each member organization to identify challenges and goals that they are currently facing. Two were found in common among all members of the partnership. The first was a need to measure accomplishments in terms of outcomes in addition to outputs (e.g., output of acres under conservation treatment and an outcome based on improvements in fish populations). The second was a need to find more effective ways to get residents to make desired changes (e.g., looking at other approaches besides farm bill programs to encourage farmers to make changes in their farming practices). The partners decided to use a "results chain" approach in order to understand the current strategies that are being used to address natural resource conservation and identify a future direction.

Assessment of Collaborative Capacity

IWR worked with Dr. Stephen Gasteyer (MSU Department of Sociology) to assess the motivations and causal models of NRWG members for participation in periodic meetings and coordinated actions. The rationale is that this group has the potential to provide coordinated leadership in addressing longstanding problems of surface water quality impairment in key watersheds: River Raisin; Western Lake Erie; Shiawassee/Saginaw Bay.

This research assessed the collaborative capacity of a multi-institutional collaboration to address disproportionality in water quality impairment in Michigan watersheds. The key finding was that 1) there is real interest in collaboration, 2) there is diversity in interest in collaboration, 3) the challenge of maintaining the collaboration will necessitate a continued focus modeling and intensification of voluntary approaches to land management.

Strategic Doing

In order to take action to address our common challenges and goals, the NRWG enlisted the assistance of Robert Brown, Associate Director of University-Community Partnerships, Michigan State University Outreach and Engagement. Mr. Brown led the NRWG through a process based on Strategic Doing. According to the Purdue Center for Regional Development, Strategic Doing is "a set of principles, practices and disciplines for implementing strategy in a network." (Strategic Doing: The Art and Practice of Strategic Action in Open Networks, Staff Publication 2010-1, Ed Morrison, Purdue Center for Regional Development, February 2010). The NRWG started with a framing question: *How do we use our assets and resources to develop innovative ways to change behavior on rural lands within the River Raisin and Shiawassee River watersheds resulting in improved water quality, benefiting human health and fish communities?*

After identifying assets that each member of the NRWG is willing to share, the group developed seven outcomes that should be accomplished together. These include:

1. Develop guiding system for decision making/process
2. Use results chain to determine additional data layers that would be pertinent to this analysis
3. Select, prioritize and depict specific rural geographic areas for action
4. Engage farmers and land owners as partners to change land practices
5. Increase knowledge of available sources of funding for activities at hand
6. Engage stakeholders that can either encourage or inhibit practice change (supply chain stakeholders and policy stakeholders) as partners to change land practices
7. Identify and disseminate existing and new knowledge

Current actions

After completing actions 1 and 2 during the previous year, the NRWG proceeded to complete action number 3 within the Shiawassee and River Raisin watersheds in Michigan in the following months. The geographic units used in the prioritization were watersheds, specifically at the HUC-12 level, and were presented to the group toward the end of 2014.

The NRWG was been able to efficiently work toward completing actions 4 and 5 in the last year as well. While reviewing results of the prioritization analysis, several members of the NRWG realized that these efforts would couple well with a proposed Great Lakes Restoration Initiative project, titled "*Cooling the Hot Spots*." This proposed project involved a pay-for-performance process for reducing phosphorus and the creation of a farmer advisory council in the River Raisin watershed, to engage farmers to join the program and raise awareness about water quality issues within the Western Lake Erie Basin. This grant was awarded by the EPA to the Stewardship Network at the end of 2014 and is currently underway. The MSU-IWR is providing technical and decision support expertise to the *Cooling the Hotspots* project.

Research Projects

The following projects represent activities supported with over $2 million dollars from our partners. USGS 104b projects are covered in other sections of this report.

<u>GLRI - Flint River Nutrient Reduction: Focusing Action</u>
The "Flint River Nutrient Reduction: Focusing Action" Project, funded through EPA by the Great Lakes Restoration Initiative, provided enhanced mapping technology, technical assistance and outreach efforts to agricultural conservation technicians in the Saginaw Basin. The project, which concluded in September 2014, sought to achieve a larger beneficial impact on agricultural non-point source (NPS) pollution using conservation prioritization tools that would be attained using traditional approaches. The ELUCID decision support system, described later in this report, was developed with stakeholder input and used by field technicians to identify and target farm fields prone to nonpoint source pollution. Two trainings were provided on ELUCID and other decision support tools in 2014. A survey of trainees found that over 80% of respondents agreed that the system would help them work with producers to place BMPs on high risk areas. As a result of this project, conservation practice implementation can be focused on farm fields having the greatest impacts on water quality, ultimately resulting in a reduction of soluble phosphorus loading in the Saginaw Basin.

The following five recommendations were included in the project's final report to improve the decision support tools:
Recommendation #1 – expand the availability of ELUCID beyond the Saginaw Basin. There is interest in doing this as evidenced by the inquiry from MSU-E for use of the tool in Southeast Michigan.

Recommendation #2 - integrate tools such as GLWMS with ELUCID to provide technicians and other users with the ability to move seamlessly from watershed scale analysis to local treatment.

Recommendation #3 – procure missing or incomplete data layers, especially LiDAR. LiDAR was used to identify areas of concentrated flow and likely areas of ephemeral gully erosion. This analysis was of great interest to the field technicians since ephemeral gullies, by definition, are not present at all times. The gullies can occur in standing crops which makes them hard to locate on site and they may be located in remote areas that are time consuming to physically investigate. LiDAR is currently not widely available in Michigan.

Recommendation #4 – test and refine the algorithms for identifying concentrated flow and ephemeral gully locations.

Recommendation #5 - look for opportunities to work with additional conservation organizations (such as the Flint River Watershed Coalition) and Conservation Districts, and help them access and utilize the tools built, demonstrated and utilized in this GLRI project.

USDA-NIFA Grant
An Integrative Decision Support System for Managing Water Resources under Increased Climate Variability

The goal of this project is to develop and disseminate a Decision Support System (DSS) that incorporates outputs from a diverse set of hydrologic systems models, analytical tools and processes which examine future climactic scenarios. Using the DSS, policy-makers, water resource managers, and agricultural producers will be able to consider varying climatic conditions while developing sustainable water strategies within communities and planning for agricultural water uses. Significant components of this project are the assessment of water users to determine and understand their capacity to accept and make behavioral modifications regarding water use as well as the involvement of key individuals and groups that represent the policy-makers, managers and water users during the various stages of the project. Modeling is ongoing during this phase of the project and water user assessments will begin in 2015.

A major outcome of the project will be to assess the implication of these scenarios on Michigan's legislated Water Withdrawal Assessment Tool and process. Furthermore, public engagement and dissemination of the knowledge gained from the project's efforts through enhanced educational programs to be develop and offered by Michigan State University and the expertise provided by Michigan State University Extension.

Red Cedar River Watershed
The IWR lead the development of a watershed plan for the Red Cedar River Watershed, located in Ingham and Livingston Counties, Michigan. The Red Cedar River Watershed Management Plan (WMP) represents the culmination of a two and a half year collaborative process designed to address existing and potential pollutants in the Red Cedar River. The process included data collection and analysis, an extensive watershed inventory effort and stakeholder involvement. The WMP describes the watershed and water quality issues within it, including the existing TMDLs that have been established for *E. coli* bacteria and dissolved oxygen. Subwatersheds within the Red Cedar are described in detail, and best management practices for addressing nonpoint sources of pollutants within subwatersheds are included as a critical component. The subwatersheds are prioritized using a scoring system to focus implementation activities in the next phase of the watershed planning process.

Spatial Decision Support Systems (SDSS)

Decision Support System: Environmental Learning Using Computer Interactive Decisions (ELUCID)
A comprehensive, web-based interactive decision support tool was developed to assist local technicians in addressing critical areas. Using this system, technical staff are able to identify land units on which to focus limited resources and determine BMPs most effective at reducing agricultural non-point source pollution.

The tool is Environmental Learning Using Computer Interactive Decisions (ELUCID), http://elucid.iwr.msu.edu/. One of ELUCID's greatest assets is its ability to engage and inform different user groups and address multiple issues in one system. ELUCID can be linked to existing systems to enhance its analytical capabilities. Engagement
The ELUCID system, along with water quality monitoring data, helps engage the community at large. The system was utilized by the Flint River Watershed Coalition in their general outreach and their K-12 water quality monitoring program, Flint River GREEN. Classrooms participating in Flint River GREEN conduct water quality sampling in their local river or stream, analyze their results, and report their findings at an annual summit. Incorporating ELUCID into these activities provided teachers and students with opportunities to consider how spatial and landscape characteristics influence water quality.

Great Lakes Watershed Management System (GLWMS)
With support from The Nature Conservancy and the U.S. Army Corps of Engineers, IWR has continued to enhance watershed-scale and field-scale analysis of water quality in the Great Lakes Basin. The Great Lakes Watershed Management System (GLWMS) (www.iwr.msu.edu/glwms) combines water quality model outputs from Purdue University's Long-Term Hydrologic Impact Assessment (L-THIA) tool and IWR's High Impact Targeting (HIT) system within a single mapping interface. Users are able to generate estimates of sediment and nutrient loading at various watershed scales and run field-scale scenarios of land cover change and best management practices (BMPs). Users can digitize areas of change or BMPs, view upland contributing areas, estimate loading changes, and save results within an on-line database. They can also generate reports showing cumulative loadings/savings over time across projects. The GLWMS is currently available for the Fox River Basin in Wisconsin, the Saginaw River Basin in Michigan, the Maumee River Basin in Ohio, and the Genesee River Basin of New York. The River Raisin watershed was added to the system in early 2015. Additional support from The Nature Conservancy will allow for the addition of a ground-water recharge scenario modeling within the Saginaw River Basin in the coming months. Future enhancements to the GLWMS may include wind erosion and phosphorus prediction tools that are currently being explored.

Train the Trainer - High Impact Targeting (HIT)
In 2012, the US Army Corps of Engineers (USACE) worked with the IWR and Purdue University to develop training materials (e.g., manuals, tutorials, fact sheets, powerpoints and a 10-part video tutorial series) for the High Impact Targeting (HIT) and Long-term Hydrologic Impact Analysis (L-THIA) online systems. These systems were originally developed by the IWR and Purdue University for the USACE Great Lakes Tributary Modeling 516e Program. This collaboration was an effective and efficient method to further disseminate the online tools throughout the Great Lakes and educate end users. The USACE Buffalo District recently incorporated the train-the-trainer materials into their Sediment Transport Analysis and Regional

Training (START) program, launched in early 2015, which offers free trainings to stakeholders across the Great Lakes. They anticipate that they will have conducted over 30 trainings by the end of the 2015 fiscal year, demonstrating the far-reaching impact of this initial project.

Building a Great Lakes Basin-Wide IT/Decision Support/Networking System

Great Lakes Clean Communities Network (GLCCN) | www.iwr.msu.edu/glccn
Big change is possible when people work together, generate new ideas, and forge partnerships. That's the goal of the **Great Lakes Clean Communities Network (GLCCN)**, an effort funded by the Great Lakes Protection Fund, where leaders connect in new and powerful ways, and determination drives innovative ideas to address environmental problems locally and throughout the Great Lakes.

The GLCCN will build synergy and find better solutions by working together and helping to make the Great Lakes healthier. The Network will enhance connectivity among organizations, bring leaders together, and facilitate the sharing of knowledge, tools, programs, and successes. More people joining around a common cause builds capacity and accelerates innovative solutions to difficult problems the Great Lakes face.

The GLCCN, being developed by the IWR, will launch later in 2015. Almost 280 individuals have expressed in interest in joining the Network once it launches. The online site will feature a database of over 70 interactive tools that address various Great Lakes issues, an interactive map for users to connect with other members of the Network, and the EcoScore, a scorecard used for tracking ecological health in Great Lakes communities. The GLCCN will be utilized in future efforts at the IWR to further disseminate research, decision support tools and other resources to stakeholders across the Great Lakes.

Methodology

Research Methods/Experimental Procedures
The manner in which we have engaged in team efforts with the scientific community from across campus, the state and region has been effective and provides an approach upon which we can build. As previously mentioned, we have an evolving process which will help us to transform IWR to more effectively address "wicked" problems. The advisory body, described below, will be critical in guiding the re-creation of IWR activities, which will lead to more holistic and effective approaches for addressing "wicked" problems. These various inputs will guide our initial activities. In addition to its staff members who have expertise in a broad array of water resource management topics, including database development and information systems, GIS, aquatic ecology and community-based water management programming, IWR has historically worked with many diverse faculty members representing a broad cross section of water resource expertise across MSU colleges. A listing of the faculty members and students who have recently worked with and received support from IWR on various water resource management projects was included in a recent report compiled for the Water Resources Partnership, a jointly funded agreement with the Michigan Department of Environmental Quality and MSU.

Our first achievement strategy is to build on and transform current IWR strengths, partnerships, and reputation. By working in a co-creative framework with individuals, policymakers and organizations to integrate the science and knowledge base, IWR is generating adaptive and dynamic systems for management of critical water resources that includes ecological, social and economic components.

(1) Reorganize IWR to more effectively link knowledge with action, i.e., connecting knowledge generation and local applications by becoming an appropriately structured boundary organization. The structure depicted in Figure 1 shows that IWR will not only serve as a critical link between the research and knowledge generated by the scientific community (i.e., entities at the University) and the user community, but will also serve to facilitate the co-creation of knowledge (middle column, Figure 1) by working with the end users (right column) and the scientific community (left column).

(2) Actively be involved in facilitating, leading, demonstrating and evaluating the co-creation process through numerous specific activities involving “wicked” problems. Water resource management with consideration for economic development is a complex problem because it often demands organizations/stakeholders at all levels to come together and find acceptable solutions to issues. Such solutions may also evolve over time when agreed upon by the parties involved. Integrating sciences into this dynamic social process and utilize modern technologies to facilitate communications and problem solving is the grand challenge we face as university researchers and technology transfer professionals. As a boundary organization, our objective is to be uniquely positioned to work across disciplinary boundaries and bring advanced sciences and technologies into decision makers' hands. Since there is a large gap between academic research and real world operational applications, bridging this gap and streamlining research and the technology transfer process is a major task for IWR . The efficient and effective utilization of modern technologies such as advanced Information and Communication Technology (ICT), GIS and numerical modeling is the key to achieve this objective.

(3) Develop decision support systems that provide support for knowledge users to make more informed decisions based on input from the knowledge generators. As we move from the traditional PC-based computing era to a new Internet-based cloud computing age with millions of mobile computing devices coming online at an accelerated rate, we have tapped into developing a new generation of water resource decision support and knowledge systems that can take advantage of recent advances in cyber infrastructure, social networking, geospatial technologies and numerical modeling and associated scientific visualization technologies. To implement this new generation of systems, we must analyze the needs of different target audiences such as federal, state and local government agencies, NGOs, various environmental organizations and the general public. It is critically important that we bring environmental knowledge producers and consumers together under the same overarching umbrella and provide tools for them to work together in a mutually beneficial manner. We need to understand their needs and concerns and address them appropriately.

(4) Guide development of this new bridging structure through an external advisory body, representing a cross-section of users and scientific groups. This advisory body will have integrative and dynamic roles in providing guidance and ideas to communities of users. The scientists involved will provide connections to clusters of water expertise from the following: multiple units within CANR, such as the Center for Water Sciences and

Department of Biosystems and Ag Engineering; other colleges, such as Natural Science and Civil and Environmental Engineering; and, external partners including the USGS Great Lakes Science Center, The Nature Conservancy and others.

(5) Provide an inclusive environment to facilitate a sense of trust among the knowledge users so they can effectively interact with the knowledge generators, creating an atmosphere and functionality where there is successful communication, translation, mediation, and adaptive process outcomes.

(6) Actively inform and partner with NGOs (with emphasis on TNC) and other funding agencies such as EPA, GLPF (Great Lakes Protection Fund), US Army Corps of Engineers, etc., to aid in acquiring support of IWR activities. These partnerships will help to add new funding sources to IWR's existing broad portfolio of funders to facilitate an expanding base of fiscal support.

Literature Review

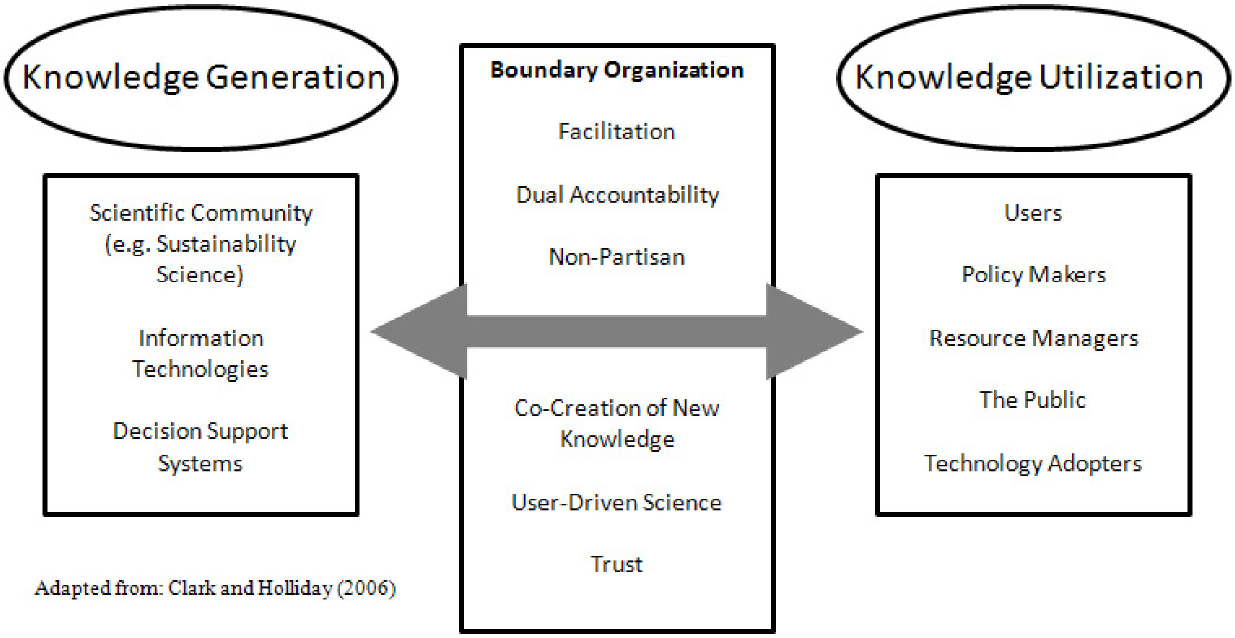

Figure 1. Boundary organization: Linking knowledge with action

All social, economic and environmental factors in a watershed need to be considered in a holistic approach to determine proper actions to manage water resources (Heathcote 1998; Gregersen et al., 2008). Watershed management often involves multiple stakeholders with conflicting interests. These stakeholders can have radically different perceptions of the problems and potential trade-offs associated with finding solutions because of dynamic social, economic, and political factors as well as biophysical complexities of water resource issues. This complex nature of water resource management and other related issues, such as global climate change or health issues, is often referred to in the scientific community as wicked problems (Batie, 2008). These types of problems are so named because they are usually difficult to solve due to their complexities and changing nature and often may create other problems as the initial ones are being addressed.

Research on wicked-type problems suggests that a comprehensive knowledge system sustained by a boundary organization is essential (Cash et al., 2003). Boundary organizations act as intermediaries between science and policy because they fulfill or possess: 1) specialized roles within the organization for managing the boundary; 2) clear lines of responsibility and accountability to distinct social arenas on opposite sides of the boundary; and 3) a forum in which information can be co-created by interested parties (Cash et al., 2003). Ingram and Bradley (2006) define boundary organizations as those situated between different social and organizational worlds, such as science and policy. Guston (2001) list three conditions often attributed to successful boundary organizations. “First, they must provide incentives to produce boundary objects, such as decisions or products that reflect the input of different perspectives. Second, they involve participation from actors across boundaries. Third, they have lines of accountability to the various organizations spanned by the boundary organization.” According to Batie (2008), adaptive and inclusive management practices are essential to the functioning of boundary organizations, and Ruttan et al. (1991) suggests that boundary organizations serve as a bridging institution and help to link suppliers and users of knowledge.

One way to further the efforts of boundary organizations, particularly with wicked problems, is to provide tools to assist with good decision-making using science-based data. Spatial Decision Support Systems (SDSS) are a type of computer system that combine the technologies of Geographic Information Systems (GIS) and DSS to assist decision-makers with problems that have spatial dimensions (Walsh 1993). SDSS are developed to integrate data, knowledge, and modeling results to identify, evaluate, and recommend alternative solutions to spatially distributed problems (Djokic, 1996; Prato and Hajkowicz, 1999). A SDSS focuses on a limited problem domain, utilizes a variety of data, and brings analytical and statistical modeling capabilities to solve the problems. It further depends on graphical displays to convey information to the users. It can be adapted to decision-maker's style of problem solving, and can easily be extended to include new capabilities as needed (Densham et al. 1989, Armstrong et al. 1990).

In natural resource management, SDSS have proven to be effective in a variety of applications such as flood prediction (Al-Sabhan et al., 2003) and conservation program management and best management practices assessment (Rao et al., 2007). Al-Sabhan et al. (2003) argued that a web-based hydrologic modeling SDSS can help solve problems such as limited accessibility by non-experts and the public; lack of collaboration support; and costly data acquisition and communications. They further indicated such system can offer openness, user friendly interface, transparency, interactivity, flexibility, and fast communication and be directly accessible to a broad audience including decision makers, stakeholders and the general public.

Objectives

(1) IWR continues its restructuring to more effectively link knowledge with action, i.e., connecting knowledge generation and local applications by becoming an appropriately structured boundary organization.
(2) Continues its active involvement in leading, demonstrating and evaluating the process through numerous specific activities involving "wicked" problems.
(3) Enhance current and develop new decision support systems that provide support for knowledge users to make more informed decisions based on input from the knowledge generators.
(4) Augment development of this new bridging structure through an external advisory body, representing a cross-section of users and scientific groups.
(5) Enrich the evolving inclusive environment to facilitate a sense of trust among the knowledge users so they can effectively interact with the knowledge generators, creating an atmosphere and functionality where there is successful communication, translation, mediation, and adaptive process outcomes.
(6) Continue to actively inform and partner with NGOs and other funding agencies to aid in acquiring support of IWR activities. These partnerships help to add new funding sources to IWR's existing broad portfolio of funders to facilitate an expanding base of fiscal support.

Plans to Disseminate Information from Stated Research

IWR has effectively worked with a variety of organizations and audiences. This has allowed IWR to build a diverse network of partners. As a complicated and wicked problem, effective water resource management requires solutions from the broad economic sectors it affects. With partners from the university, government, non-government, and private sectors, IWR will receive the input needed to reorganize itself as a boundary organization, bridging the gaps between each of the sectors. IWR will work with its partners and internally to co-create solutions to the complex problems posed by water resource management and disseminate this information through its well established technology transfer program, as well as through its decision support systems, regional networking, social networks and facilitation capabilities. Advisory body inputs will be critically important in defining targets, timelines, and expected impacts. This reorganization can evolve largely within our existing financial and personnel structures.

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Assessing Co-Creation of Knowledge Generation and Diffusion Approaches

Basic Information

Title:	Assessing Co-Creation of Knowledge Generation and Diffusion Approaches
Project Number:	2014MI228B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	8
Research Category:	Social Sciences
Focus Category:	Management and Planning, Water Quantity, Water Quality
Descriptors:	None
Principal Investigators:	Stephen Gasteyer

Publication

1. Gasteyer, S. 2015. Assessing Co-Creation of Knowledge Generation and Diffusion Approaches, WRRI, Institute of Water Research, Michigan State University, East Lansing, MI 48823, 3pgs.

Title: Assessing Co-Creation of Knowledge Generation and Diffusion Approaches

Project Number: 2014MI228B
Start: 03/1/2014
End: 02/28/15 (actual)
Funding Source: USGS ("104B")
Congressional District: eighth
Research Category: Social Sciences
Focus Categories: Management and Planning, Water Quantity, Water Quality
Descriptors: NRWG, WWG, Mapping, interview tool, key indicators
Primary PI: Stephen Gasteyer, Michigan State University

Project Class: Research

Introduction

This project involved collaborative work with the Natural Resources Working Group (NRWG) to develop an innovative model of adaptive learning to address nutrient runoff in Michigan – specifically in the River Raisin and the Shiawassee River and Saginaw Bay Watersheds. The work involved 6 meetings with state government, basin level agency, and nongovernmental organization representatives and MSU staff and scholars to develop a white paper outlining an adaptive management strategy. The outputs are: meetings attended, presentations made, white paper in draft. The outputs include: collaborative learning about the feasibility and opportunities for collaborative co-creation of knowledge to address nutrient management and water quality in Michigan.

General Statement

Problem/Demand

The year 2014 has highlighted the urgency of addressing the impacts of nonpoint source water quality impairment in the Midwest. In August, blue-green algae rendered the public water supply toxic for roughly 400,000 people in metropolitan Toledo, Ohio and southeastern Michigan due to the contamination of source water in Lake Erie. The River Raison flows into Lake Eerie and as such contributes to water quality impairments. Likewise, nutrient loading has been a major challenge in the Shiawassee River Watershed and the Saginaw Bay in Lake Huron. It is important to note that agriculture was not the sole cause of the crisis. Still, agriculture is an important contributor and scientific evidence supports that nutrient loading in the waterways has increased. Further, there is reason to believe that nutrient management in agriculture will only become more difficult in the future as a predicted impact of climate change will be greater numbers of extreme rainfall events and extended growing seasons, both of which could exacerbate runoff challenges.

The goals of this project was to use a collaborative forum of state government, non-governmental watershed/conservation organizations, advocacy organizations for key stakeholders (farmers and environmentals), and MSU staff and scholars to develop a new framework that draws on local knowledge in addressing water quality and nutrient runoff issues.

Methodology

The method used was a series of working meetings with the stakeholders mentioned above. In the development of the white paper, we drew on methods employed by participants in the meetings in the assessments of land use, hydrology, water quality, and the adoption of actions by farmers. These were applied in the development of the white paper.

Problem and Research Objectives

Given changing ecological, as well as political and economic conditions, the aim of interventions should be to set up systems that foster partnerships that support continuous learning and adaptation.

With the guiding principles of context based actions, participatory approaches, establishment of partnerships to support continuous learning and adaptation, the ultimate goal of the project was to develop an action document for fostering community based natural resources management. Community based natural resources management engages local actors in managing natural resources, including deciding on what behaviors should change to maintain and improve natural resource quality and what actions would be necessary to encourage behavior change (in this case around watershed management).

Principle Findings and Significance

The White paper is not completed, but we have developed a draft model of actions to facilitate community based natural resources management to minimize water quality impairment.
The partners then jointly identify actions necessary to address those issues, and develop or employ existing institutions to assist in undertaking those actions (in this context probably facilitating communication among existing agricultural assistance agencies). Finally, the researchers and community partners develop indicators for the effects of actions taken. This approach requires that trust be established and maintained between local actors and the researchers, and involved parties must be able to see evidence of positive outcomes from actions taken.

Adapting this model to our own actions, these are the steps that as partners participating in community based natural resource management in these watersheds, the NRWG needs to take:

1) Design and structure the innovative information gathering techniques, determine the participants, and take actions to build trust.
    a. Using mapping techniques
    b. Gathering information from existing water quality programs
    c. Holding listening sessions with key actors such farmers associated with the MAEAP program.–
2) Gather information from farmers and others including:
    a. What type of information do you need to encourage behavior changes that address natural resource management problems?
    b. How would that information be best presented?
    c. What are effective motivations to change behavior in this context?
3) Develop innovative processes, tools, and information pieces for use:
    a. By local farmers and decision makers

b. In groups settings – including legislative conferences; in class for Restricted Use Pesticide (RUP) credits

4) Work with existing and help form new institutions to implement actions (information development, presentations, facilitating access for farmers to resources to implement practices).
5) Indicate outcomes -- develop indicators and monitor outcomes – (e.g. local study circles established, practices implemented, enrollment in cost-share programs, practices implemented, dollars leveraged, measurable changes in water quality).
6) Replicate processes to other areas/actions
   a. Work with existing institutions to write up results and present/disseminate to broader audiences.
   b. Work with existing institutions with local resources to implement

Notable Achievements

1) The white paper is in draft:

Title: Modeling Participatory Water Quality Impairment Research with Farmers

Brief: lays out a model for community based natural resources management at the watershed level to address water quality issues.

Funding Agency: USGS

2) Work on the White Paper led to the successful proposal development of project grant $791,600.00

Title: Cooling the Hotspots: Motivating Farmers to Reduce Nutrient Losses

Brief: A multi-institution project involving Land Stewardship, River Raisin Conservation District, University of Michigan, Michigan State University that will identify areas of water quality impairment and develop strategies with farmers and other key land owners to address water quality impairment.

Funding Agency: EPA Great Lakes Restoration Initiative and The Great Lakes Water Quality Agreement

Publications

None over the last year.

Improving Capacity to Collect Crowdsourced Hydrologic Data through Focused Engagement and Enhanced CrowdHydrology Software

Basic Information

Title:	Improving Capacity to Collect Crowdsourced Hydrologic Data through Focused Engagement and Enhanced CrowdHydrology Software
Project Number:	2014MI229B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	8
Research Category:	Social Sciences
Focus Category:	Education, Management and Planning, Methods
Descriptors:	None
Principal Investigators:	Jeremiah A Asher

Publications

1. CrowdHydrology, Inc. 2015. CrowdHydrology [Website]. Available from http://www.crowdhydrology.org.
2. Lowry, C.S. 2014. CrowdHydrology Gage Station Installation Guide.
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4. Young, L. 2014. CrowdHydrology in Michigan Fact Sheet.
5. Asher, A., L. Young, C.S. Lowry. 2014. Improving Capacity to Collect Crowdsourced Hydrologic Data through Focused Engagement and Enhanced CrowdHydrology Software, Institute of Water Research, Michigan State University, East Lansing, MI 5pgs.

Title: Improving Capacity to Collect Crowdsourced Hydrologic Data through Focused Engagement and Enhanced CrowdHydrology Software

Project Number: 2014MI229B
Start: 03/1/2014
End: 02/28/15 (actual)
Funding Source: USGS ("104B")
Congressional District: eighth
Research Category: Social Sciences
Focus Categories: Education, Management and Planning, Methods
Descriptors: crowdsourcing, citizen water science, stream stage monitoring
Principle Investigators: Aaron Jeremiah Asher, Institute of Water Research, MSU; Christopher S. Lowry, Department of Geology, University at Buffalo – The State University of New York

Project Class: Research

General Statement

Problem and Research Objectives

In a state seemingly surrounded by water, it can be difficult to generate interest and concern about the need for sustainable management of Michigan's water resources when not experiencing drought conditions. While Michigan has developed an innovative Water Use Program to quantify and regulate large quantity withdrawals (LQWs), tensions are escalating amongst the regulated water use community and the general public. Specifically, there is growing concern from citizens that the proliferation of agricultural irrigation and controversial high-volume hydraulic fracturing operations are negatively impacting local watersheds. On the other hand, regulated water users in certain areas of the state are finding it more difficult to meet the requirements of Michigan's Water Use Program to develop or expand their high capacity water withdrawals. Complicating matters is the MDEQ ability to effectively run the Water Use Program with limited staff and funding support and at the same time facilitate additional data collection and monitoring efforts. It is imperative that the public and water users better understand their local hydrologic systems in light of these challenges to calm fears and reveal appropriate and productive actions. These challenges pose a great opportunity to crowdsource hydrologic data using the CrowdHydrology project, which collects stream stage measurements via text messaging and a recently released smartphone app. Crowdsourcing can engage and inform concerned citizens and is an affordable approach for data collection. This information may provide supplemental data to local and state agencies, in addition to engaging the public in understanding and monitoring Michigan's water resources.

The CrowdHydrology approach to monitoring may provide a more accessible pathway for citizens to understand and participate in water science as well as collect measurements of stream stage during base flow events. Data collected through CrowdHydrology could also be examined for use within the Water Withdrawal Assessment Process to supplement existing USGS gage data and to build a better database for inland lakes data.

The objectives of this project were to:

- Expand the CrowdHydrology monitoring network in Michigan
- Increase public awareness about Michigan's water resources and management
- Enhance the CrowdHydrology code and user experience to increase participation

Methodology

Two Michigan CrowdHydrology user workshops were held on June 26, 2014. Participants were introduced to the CrowdHydrology concept and trained on the installation process. The workshops also discussed topics ranging from the value and use of hydrologic crowdsourced data to quantifying uncertainty. Main objectives of these workshops included connecting users from different backgrounds in citizen science, developing a sustainable CrowdHydrology monitoring network in Michigan, and determining the best methods to increase the use of crowdsourcing of hydrologic data.

In order to make stream measurements more usable and better integrated into existing mapping software and online services, a preliminary investigation for integrating stream measurements into a standardized data format was conducted. The team developed a program that would allow CrowdHydrology data to be seamlessly integrated into online mapping applications and ESRI GIS software products. This integration will open up opportunities to more easily share and analyze the collected data.

In addition, an interface was developed that allowed users of the system to select monitoring stations of interest and submit a request for data. The new interface creates a downloadable package containing an ESRI shapefile with geographic information and associated tables with staff gage readings. Prior to the project users were unable to download this data in geographic format for more advanced analysis.

The Social.Water code was updated in order to allow users to view measurement statistics and streamline the processing of incoming water level data. As part of this project an undergraduate student in computer science was hired at the University at Buffalo (UB) under the supervision of Dr. Lowry at UB and Dr. Mike Fienen at the USGS Wisconsin Water Science Center. Code updates allowed users to view when the most resent measurements were made and the total number of measurements at each station. The updated code also triggers station maintenance messages that inform lead personal both at the University level and within watershed groups when received text messages indicate gage maintenance is needed. Social.Water is an open source collaboration and all code modifications were fully documented and available to other users via GetHub (Fienen and Lowry 2012). The Social.Water code is run on a dedicated server at the University at Buffalo provided by a grant through the Verizon Wireless Foundation.

Principle Findings and Significance

Expanded CrowdHydrology monitoring network in Michigan

Thirteen gage installation kits were provided to workshop participants who were willing to install and maintain a CrowdHydrology gage. The project team decided this would be a more effective way to enhance the Michigan CrowdHydrology gage network versus targeting only three watersheds as described in the original proposal. The majority of the participants indicated that they would like to install additional gages within their watershed in the future. An unforeseen permitting issue, described later in this report, has delayed gage installation.

Materials for another 23 gage kits were purchased. At the time of writing, three gage kits have been distributed to three other nonprofit organizations. The Institute of Water Research plans to install eight gage kits in southwest Michigan once the permitting process has been finalized. The remaining 12 gages will continue to be distributed to additional groups at a first come, first serve basis. Preference will be given to groups who have not yet received a free kit. Once all gages purchased through this project have been distributed, permitted and installed, the CrowdHydrology monitoring network in Michigan will expand by 36 sites.

Increased public awareness about Michigan's water resources and management
Sixteen participants from nine watersheds attended the user workshops, representing watershed groups, conservation organizations, nonprofits, state agencies, municipal groups and volunteers. Thirteen of these individuals agreed to install and maintain a CrowdHydrology site and were provided with a gage kit. Not only did participants learn about crowdsourcing hydrologic data, but discussed the potential for CrowdHydrology to engage their constituents in new ways. Participants were encouraged to "market" their gages through newsletters and social media to further increase awareness and foster additional data contributions. It is expected that citizens participating in CrowdHydrology will become empowered as they contribute hydrologic data and develop an understanding of their local streams and rivers.

The project team also met with various government organizations regarding the CrowdHydrology concept. The MDEQ saw potential for piloting CrowdHydrology in various efforts, including their dam safety program. MDEQ subsequently invited the project team to discuss CrowdHydrology with their Water Use Advisory Council, a multi-interest stakeholder group established to advise the MDEQ on the state's Water Use Program. The Council included CrowdHydrology in their final report as a method to collect data on inland lake levels. A copy of the final report is available here:
http://www.michigan.gov/documents/deq/WUAC_Final_Report_12_12_14_478427_7.pdf

The project team also presented to the Michigan Silver Jackets team, a group working to develop a flood risk management program for Michigan with coordination provided by the U.S. Army Corps of Engineers. These additional outreach efforts attracted further attention to CrowdHydrology and spurred interest and new opportunities with groups that did not participate in the user workshops.

In developing these relationships with current and future users, we will continue to investigate the most effective methods to generate participation and collect distributed hydrologic data both for public and scientific use. Stakeholders provided valuable feedback with regards to additional strategies for collecting data. Below is a summary of suggestions:

- Add a QR code to CrowdHydrology signage
- Use gamification principles to increase participation (e.g., leaderboards for top data contributors)
- Develop an alert for smartphones that indicates when users are near a gage

- Allow users to take a picture of the gage (now available with a smartphone app developed by Michigan Technological University students)
- Make metadata available online (e.g., reference elevation)
- Partner with organizations that may have survey equipment when establishing a reference elevation and tie back to USGS benchmarks when possible
- Resurvey gages in spring in case of gage movement due to ice

Enhanced CrowdHydrology code and user experience to increase participation
It is anticipated that the completed enhancements to the Social.Water code and user interface will foster additional interest and participation in CrowdHydrology as user-friendliness and functionality are improved. Updating the code and mapping environment utilized in CrowdHydrology allows users to extract additional information from the website and enrich their ability to interact with and share CrowdHydrology data.

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Lowry, C.S. and M.N. Fienen. 2013. CrowdHydrology: Crowdsourcing Hydrologic Data and Engaging Citizen Scientists. Groundwater 51(1): 151-156.

Notable Achievements

The project team initiated an extensive process with the MDEQ to lessen the burden of permitting requirements for CrowdHydrology users. It was discovered after the user workshops that permits are required in Michigan for staff gages. After initial meetings with the department, it was determined that the gages could not be exempted from the permitting requirement without legislation. The project team worked with the MDEQ to assess alternatives such as statewide permits, and ultimately determined that having local organizations (e.g., watershed, conservation or municipal groups) lump multiple gages under one permit by watershed was the best solution. A template application was developed by the project team that contained pre-filled sections on the application along with a spreadsheet for listing out site-specific information for all gage locations. The MDEQ did not complete its review and approval of the prepared materials by the end of the grant period. At the time of this writing, the MDEQ is still reviewing materials. The project team will distribute all finalized documents to stakeholders involved with this project once approved.

The Potential for Incorporating Economics ino the Great Lakes Tributary Model (GLTM) Decision Support Tools

Basic Information

Title:	The Potential for Incorporating Economics ino the Great Lakes Tributary Model (GLTM) Decision Support Tools
Project Number:	2014MI231S
USGS Grant Number:	G14AP00032
Sponsoring Agency:	COE_MSU
Start Date:	4/1/2014
End Date:	9/30/2014
Funding Source:	104S
Congressional District:	8th
Research Category:	Water Quality
Focus Category:	Models, Management and Planning, Economics
Descriptors:	None
Principal Investigators:	Jon Bartholic, Saichon Seedang

Publications

There are no publications.

Title: The Potential for Incorporating Economics into the Great Lakes Tributary Model (GLTM) Decision Support Tools

Project Number: 2014MI231S
Start: 04/1/2014
End: 09/30/15 (actual)
Funding Source: USGS ("104S") COE_MSU
Congressional District: eighth
Research Category:
Focus Categories:
Descriptors:
Primary PI: Jon Bartholic; Saichon Seedang

Project Class: Research

General Statement

Problem/Demand

Excessive soil erosion and sedimentation delivered to surface water impair aquatic life and habitats, limit opportunities for recreation, impact human health, and increase the costs of water supply and navigation dredging. Nutrient and soil losses through erosion also affect farm operation and production. These on-site and off-site environmental effects of soil erosion have economic consequences to both farmers and society . Estimates of the economic costs of soil erosion have been reported for several countries (see Telles et al. 2011 for details). In the United States, the combined off-site and on-site cost of soil erosion from agriculture was estimated at about $44 billion at 1992 price levels (the equivalent of $74 billion at 2014 price levels), of which approximately 60 percent is on-site costs associated with a reduction in soil productivity (Pimentel et al., 1995).

In the US, while more than 50 years of conservation efforts and billions of dollars (USDA, 2006) have been spent toward working with landowners and farmers to reduce soil erosion and sedimentation through implementation of best management practices (BMPs), there is still a continuing loss of soil and non-point source (NPS) pollution problems associated with soil erosion in surface water bodies. This raises concerns among resource planners and policy makers about the effectiveness and outcomes of BMP implementation. The public, as taxpayers, need to be informed of the benefits of conservation spending, especially those off-site benefits. In addition, with higher crop prices, farmers/producers are also facing a decision whether to place their land in conservation and/or retire their land from conservation for high value crop production. As such, there is a significant need for information about the economic costs and benefits of conservation at all levels of decision-making.

Methodology

The project tasks include pre-workshop planning; pre-workshop literature reviews and reviews of available data sources; pre-workshop distribution of documents including details of the GLTM models developed to date; pre-workshop consultations with the project economic consultants and with project cooperators; conduct of the workshop; post-workshop follow-up with participants and experts; and preparation and distribution of the white paper summarizing the workshop outcomes.

Problem and Research Objectives

This scope of work is for a project at Michigan State University's Institute for Water Research that 1) conducted a workshop and 2) produced a white paper that address the potential for incorporating economic data into a decision support tool.

Principle Findings and Significance

Workshop Presentations:
The workshop convened a total of 20 experts in the areas of economics, conservation, and technology who have experience using decision support tools (see Appendix), and presented case studies of current conservation activities and the development and use of such tools, including the GLWMS.

Several workshop participants (including, Jon Bartholic and Glenn O'Neil of IWR-MSU; Jan Miller of USACE and Tom Crane of the GLC; Scott Sowa of TNC and Steven Miller of MSU-AFRE) provided presentations of case studies focused on the decision support tool development and their uses to assist conservation planning (e.g., targeting, measuring and evaluating conservation activities). Overall, economic and cost data has been incorporated, to a limited degree, into the decision support tools used in planning efforts. The following highlights a number of examples from the workshop presentations:

The GLTMP and GLC have developed two types of sediment modeling: site specific tributary modeling and web-based tools (see appendix for details). The tributary models rely heavily on technology, thus requiring technical expertise in sediment modeling, and are much more site specific. Web-based tools are more user friendly and are more appropriate for watershed level planning. The web-based tools can be used for tracking and targeting outcomes while working with producers on BMP implementation at the landscape level. Linking changes in sediment reduction in a landscape and relating them to downstream environmental improvement (i.e. water quality) is needed.

IWR presented about GLWMS, including the HIT tool, and their applications. Specifically, HIT calculates the total and rate of erosion and sediment loadings, as well as the amount of sediment or erosion reductions when applying BMPs. This tool allows users to compare sediment/erosion reduction costs to the amount of sediment/erosion reduction (dollar per ton of reduction). However, only partial costs (i.e., NRCS-BMPs standard cost) are provided for in the tool. It is anticipated that the full economic costs of conservation could be identified and built into the GLWMS.

The economic component of BMPs with enterprise budgets (EB) was presented by Steven Miller. Farmers can input their farm operation costs and income data into a spreadsheet and calculate their cost and return on a per acre basis. It may be beneficial to expand EB to include BMP costs and benefits options for farm operators, as a means to increase BMP adoption.

Farmers and resource managers would benefit by knowing the full costs and benefits, including the economic risks associated with BMP implementation. This could also facilitate discussions between resource managers and farmers about making changes to conservation policies and encourage the adoption of BMPs on farmlands.

The Nature Conservancy's (TNC) presentation focused on using adaptive management approaches to inform management of agricultural non-point source pollution at the watershed level, and provided a good use of economic analysis to complement the policy goals. TNC works with stakeholders to set achievable conservation goals, then select the most cost effective BMPs to meet those goals. There are four phases to TNC's planning strategies:

- Phase 1 – relate the health of biological communities to water quality;
- Phase 2 – relate conservation actions to water quality and the health of the biological community;
- Phase 3 – develop data and decision tools to target and track;
- Phase 4 – partner to set goals and test innovative strategies to achieve them.

It is clear that economic information in BMP decision tools have played an important role in TNC's conservation planning. Incorporating more complete information about economic costs and benefits of non-market valuation, such as fish recreation and biodiversity value, could be beneficial.

James Selegean of USACE presented the current efforts of USACE in sediment dredging. Several concerns related to sediment dredging and efforts to control sedimentation at the landscape level exist and need to be addressed. These concerns include the amount of sediment, and their source, that actually end up at the dredging point downstream. Since there are many factors related to sedimentation transport and long-term accumulation, it is also important to understand how long it takes for BMPs to have a positive effect on the reduction of sediment at the downstream dredging point. Economic information on the cost of dredging and BMP costs of sediment reduction may be linked to draw a general conclusion of the benefits of sediment reduction on land.

Adding another policy dimension, Brent Sohngen of Ohio State University (OSU) presented a model of nutrient concentrations in the Maumee and Sandusky rivers. By using data of long-term nutrient concentrations from two watersheds for the analysis, it was found that in general, the concentrations of nutrients (P-Phosphors) largely depend on nutrient inputs (P) and crop prices (corn price). However, conservation measures (conservation tillage) provided mixed results on their effect on the P concentrations in the two rivers. This may suggest that efforts to reduce P inputs to improve water quality could also be done by using tax policy (e.g. fertilizer tax). The study also spurred discussion that considered whether more regulations on phosphorus use (i.e., ban of using phosphorus in some activities) to reduce the additional pollutants entering water bodies might be a potential policy option.

The Linkages of BMPs, Costs, and Benefits:
An overview of economic considerations and linkages of conservation BMPs can be illustrated in Figure 1. BMP implementation on farmland needs quantifications of their impacts on sediment reduction, which in turn requires some physical models (i.e., SWAT model) to estimate

load reduction (i.e., amount of sediment loadings). Since most policy interests are on downstream environmental improvement (offsite benefits) on sediment reduction, there is a need to quantify the changes resulting from sediment load reduction. For example, if policy interest is the improvement of recreation fishing, it must be understood how sediment reduction will improve water quality and habitat. This requires bio-economic models to capture the chain of impacts on water quality of BMPs before and after sediment reduction. The models may include a water quality model, ecological model (fish recreation model), and/or economic model. If all changes (effects) can be measured, the estimate of BMP costs can be compared to the economic benefits of downstream recreation. Some effects of BMPs can be relatively easy to measure and economic costs and benefits can be calculated. For example, onsite costs and benefits of BMP implementation are useful for landowners and/or conservation planners for their conservation decision making.

The workshop participants also went through an exercise to identify the possible on-site and off-site costs and downstream benefits of implementing a buffer strip to encourage sediment reduction. It was clear from this exercise that identifying the full economic costs and benefits of BMP implementation, and their impacts, is not an easy task.

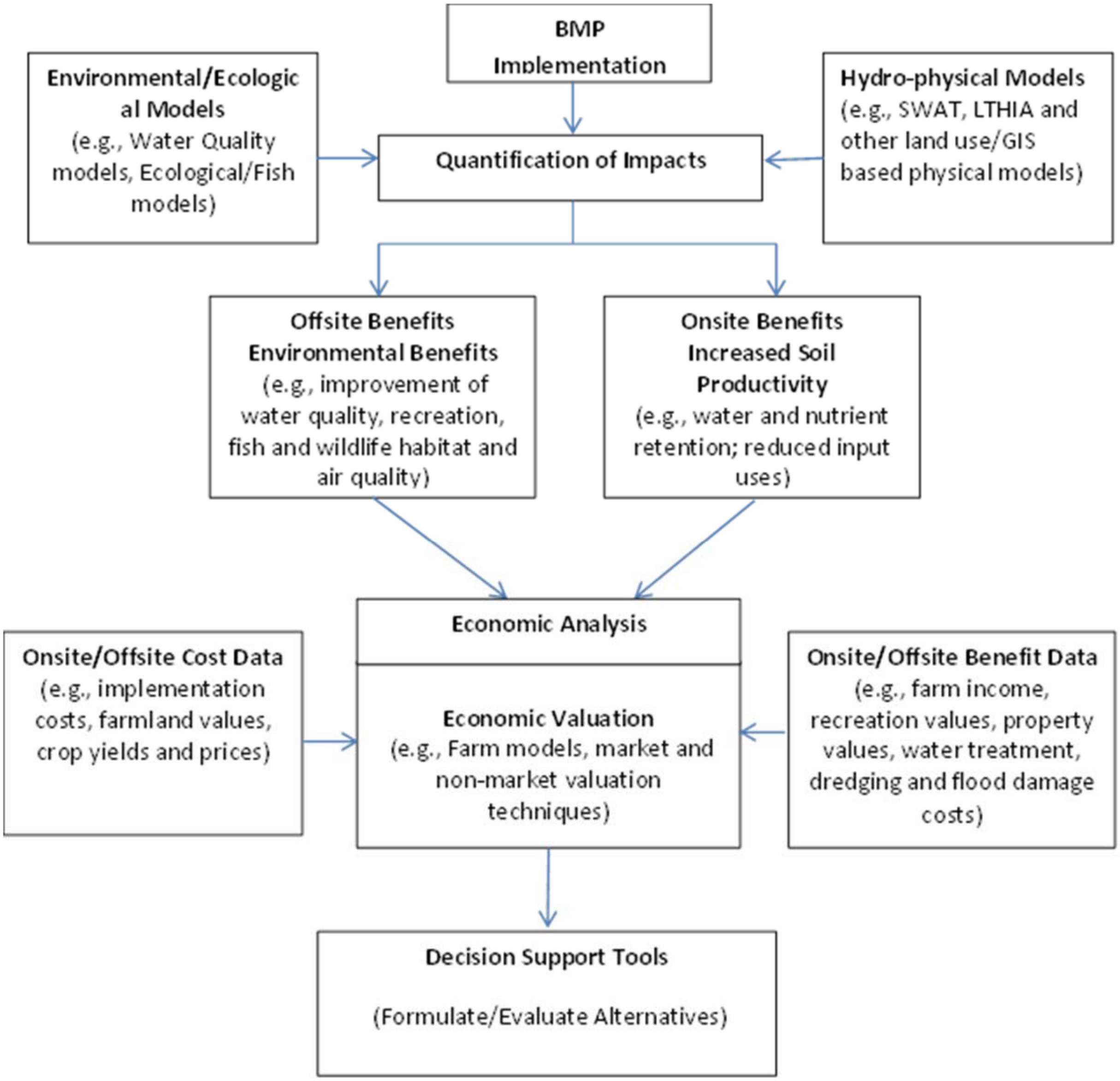

Figure 1 Onsite/Offsite Costs and Benefits of BMP Implementation with Data and Models Needed for Quantification within Decision Support Tools

Challenges of incorporating economic information into Decision support tools:

Most professionals agree that having more economic information will result in better decision making. However, obtaining complete economic information, and incorporating it in decision support tools poses many challenges. These challenges can be summarized as follows:

- Not all economic costs and benefits of conservation are easy to identify and/or quantify in monetary terms. Some costs may be relatively easy to obtain, such as per unit cost of BMP installation and operation and maintenance costs. However, the opportunity cost of taking land out of production depends on farmers and their net profits.

- The benefits of conservation are the most challenging to incorporate into decision support tools, as many of these benefits are not captured in market transactions. For example, the benefits of water quality improvement by sediment reduction may include increased biodiversity, expanded habitat for endangered species, and increased opportunities for sport fishing and recreation. Although there are available estimated economic benefit values from various studies (e.g., Hansen & Ribaudo, 2008), more site-specific values are still needed. These site-specific benefits needed to be quantified into monetary terms.

- Even if there were complete information about costs and benefits, it would be difficult to provide answers with certainty. This uncertainty relates to the difficulty of clearly demonstrating the link between upstream costs and downstream benefits of BMPs. These linkages need to be captured and quantified by models at various scales (i.e., field models, watershed hydrologic models, stream flow models, water quality models, ecological models).

- Economic information in a decision support tool can be used by various users to assist decision-making at different levels. Therefore, when integrating information into the tool, one must design it in such a way that it is appropriate for their end user's preferences. A non-industry end user (or the general public) may also benefit from using information with a simple design and easy-to-use decision tools.

- Economic costs and benefits of BMPs at a farm scale can be captured and included in a decision tool. However, obtaining the information may be problematic, due to the privacy of such information. Therefore the expanded use of the enterprise budget to incorporate BMP cost and benefit options for farmer use could be beneficial.

Summary and Next Steps:
Decision support tools can help users systematically prioritize and target areas for BMP implementation, as with GLWMS. An effort to include economic information into these tools will certainly help users compare all economic costs and benefits of their conservation decisions. Landowners, farmers, and resource managers can use the information to direct resource allocation to where they could maximize the net economic benefits. Currently, limited cost

information (primarily installation costs) has been used and integrated into the tools. Challenges to include more complete economic information into the tools are mostly due to data availability, especially the offsite benefits of BMPs. As a result, there is a need for increased research efforts and funding for several areas, including model quantification of the linkages between the impacts of BMPs on water quality improvement and the benefits to downstream users, empirical studies on non-market valuation, and techniques to develop an economic database. A greater understanding of the linkages of BMP impacts, both on costs and benefits, will result in more informed decisions on investment and funding for BMPs. In addition, other economic information for decision support tools (e.g., tax, cap, trading, subsidies, performance based incentives, conservation credits/trading, payment for ecosystem services) can be developed to assist policy makers.

A number of strategies should be pursued to improve decision tools used in the implementation of conservation practices. These strategies include:

- Economic costs of BMPs should be fully integrated into decision support tools; due to data availability and simple calculation methods, this plan should be implemented first. Some standard economic costs, such as those associated with implementation, operation and maintenance can be obtained from conservation agencies such as the NRCS; opportunity costs can be determined through the observation (survey) of farmers' willingness to adopt the BMPs. In addition, existing benefit estimates, such as those provided in the study by Hansen & Ribaudo (2008) are already available to for use and could potentially be incorporated into decision support tools.

- Many factors must be considered in any decision regarding conservation practice adoption, and economic information alone may not provide sufficient incentive to meet sediment reduction targets. Other measures, including taxation and regulation of pollution sources, could be integrated in decision support tools (e.g., tax mechanisms can help reduce phosphorus use, as suggested by research in the Maumee and Sandusky River).

- As the downstream benefits of implementing BMPs often take a long time to be realized (e.g., from physical to biological effects), the outcome of environmental improvement is often beyond the conservation program's contract term (usually 3-10 years). Therefore, conservation programs and practices which rely on contracting private landowners or farmers to implement BMPs may not be a sustainable approach. Regional restoration approaches which could be modeled and developed for decision tools, such as large-scale wetland restoration or creation, may be a better method to ensure conservation sustainability. This approach would take land out of production permanently, and could be accomplished by land acquisition and permanent easements at sites where wetlands can be restored, enhanced, or preserved in order to capture agricultural runoff.

- A new proactive voluntary conservation program, such as the 4R Nutrient Stewardship Certification Program on Lake Erie's water quality, may provide an overall reduction of conservation cost and ensure sustainability of conservation benefits. This approach encourages agricultural retailers, service providers and other certified professionals to adopt proven best practices. It provides a science-based framework for plant nutrition management and sustained crop production, while considering specific individual farms' needs (see http://4rcertified.org/about/).

Notable Achievements: N/A

Publications: N/A

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Information Transfer Program Introduction

Providing dependable, accurate and unbiased science-based information to clientele and partners is a key component of the Institute of Water Research's (IWR) Information Dissemination program. As information from numerous and unverified sources becomes increasingly accessible over the internet, it is critical that the IWR program as well as any information that is released from the University be current, reliable, and readily transferable to stakeholders, key decision makers and non-traditional audiences. It also must be easily understood and accessible. The IWR information dissemination program transfers research-based information to these audiences in a variety of modes, and in many cases, partners with user groups to co-create and develop the programs in tandem with them. The objectives of the overall program as well as the components that make up the program are to develop and present educational programs designed to increase the public's awareness, knowledge and appreciation of the water quality and quantity problems in Michigan, to stress the environmental and economic alternatives required to solve complex and sometimes contentious water related problems, and to promote transformational education that leads to positive changes for the environment and people of the state.

Some of the formats that are used to meet the needs of diverse audiences include conferences, seminars, training workshops, computer models, web-based programs, and printed material. Some programs are targeted at specific groups while others are suitable for a diverse audience. Much of the work is collaborative with colleagues and organizations and several of the activities have been ongoing for many years. Often these programs are part of a much larger initiative. Audiences and partners include agency personnel, watershed organizations, non-governmental organizations, riparian owners, farmers, local governmental agencies, students, and University faculty. Evaluations of programs are included to assess the worth of the programs, how much was learned by participants, and help prioritize issue areas and programming/training needs for future years.

Information Dissemination and Technology Transfer Training Programs

Basic Information

Title:	Information Dissemination and Technology Transfer Training Programs
Project Number:	2014MI226B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	8
Research Category:	Water Quality
Focus Category:	Surface Water, Water Quality, Education
Descriptors:	None
Principal Investigators:	Lois G Wolfson

Publications

1. Allman, Scott, Lois Wolfson, Ken Freestone, Laura Young, and Jeremiah Asher. 2014. Great Lakes Clean Communities Network: Connect to Protect - video at http://vimeo.com/102867178
2. Wolfson, Lois. 2014. Management and Protection of Lakes Featured at Inland Lakes Convention, Michigan Natural Shoreline Partnership Newsletter, Vol 4 (3):5-6.
3. Wolfson, Lois and Ruth Kline-Robach. 2014. E. coli data analysis from the tributaries and main branch of the Red Cedar River, 319 Department of Environmental Quality Interim Report, March.
4. Wolfson, Lois. 2014. Water-Climate Decision Support System. Bulletin of the Institute of Water Research, Michigan State University. November. 2pp.
5. Wolfson, L. 2015. Information Dissemination and Technology Transfer Training Program, WRRI Institute of Water Research, Michigan State University, East Lansing, MI 48823, 4pgs.

Title: Information Dissemination and Technology Transfer Training Programs

Project Number: 2014MI226B
Start: 03/1/2014
End: 02/28/15 (actual)
Funding Source: USGS ("104B")
Congressional District: eighth
Research Category: Water Quality
Focus Categories: SW, WQL, EDU
Descriptors: Water Quality; Natural Shorelines, Great Lakes, Watershed Management; Invasive Species; Inland Lakes; Lake and Stream Leadership; Interactive Web-based Systems
Primary PI: Lois Wolfson, Institute of Water Research, Michigan State University

Project Class: Information Transfer

General Statement

Brief description of the information transfer activity:

Conferences
The 24th annual Great Lakes conference, titled "**The Great Lakes: Issues and Innovation**" focused on a variety of current and emerging issues that affect the Great Lakes ecosystem and Michigan's economy. In the past, most of the Great Lakes conferences ranged from 150-200 participants. The Great Lakes conference attracted so many new participants, including over 50 high school teachers that the room had to be changed to a larger one to accommodate attendees. Conference evaluations indicated that 94% of those filling out the form found the overall conference to be very good or excellent. Many indicated that they are returning participants, have direct connections with the Great Lakes, either through their work or through teaching, and that they will use the information gained from the conference in their current work. Partners with the Institute for this conference were Michigan Sea Grant Extension, MSU Department of Fisheries and Wildlife, and the Office of the Great Lakes, Michigan Department of Environmental Quality (MDEQ).

A partnership of the state's major players in inland lakes led to the development of the first ever statewide **Michigan Inland Lakes Convention**. The event, focusing on partnerships to protect Michigan's inland lakes, was held over a three-day period and attracted over 400 people across the state. Partners included the Michigan Department of Environmental Quality and Natural Resources, MSU IWR, MSU Extension, and three of the key nonprofit organizations in the state. The Convention presented an opportunity for lake professionals, researchers, local government officials, lake enthusiasts, and others interested in protecting water resources to participate through educational presentations, workshops, tours, exhibits, and networking. The IWR played a key role in development and organization of the Convention, hosting the web site registration, assembling materials, and moderating several sessions. A detailed evaluation indicated that people improved their knowledge and planned to use some of what they learned in other projects. Over 75% of participants indicated they increased their leadership, stewardship and confidence due to the Convention and over 90% indicated they gained information that will assist them as a professional or volunteer, and learned something new they will share with others.

IWR also helped develop the North Central Region Water Network's conference on **Extension Beyond Borders: Strengthening Networks for More Effective Water Resource Management**, held in Minneapolis, MN. Extension educators and researchers from 12 land-grant Universities were invited to network, share data and information on key water issues and coordinate efforts in writing future proposals. Over 125 people attended, with evaluations indicating the valuable nature of the conference.

Internet-Based Programs and Development of Decision Support Tools
The IWR obtained external funding for further development, enhancement, and expansion of decision support tools that help users in making more informed science-based decisions within their community or organization. The systems being developed currently utilize various models, GIS, and current and historic data to identify important environmental issues such as high risk areas for runoff and erosion or areas of high nutrient concentrations. Several of the systems also were designed to increase networking among users groups. IWR staff members created "apps" for use by agricultural producers and technicians in the field, and for use by canoers and paddlers interested in learning about their surroundings on the Grand River, the longest river in Michigan. IWR staff developed and presented training programs, tutorials, brochures, and demonstrations to help users understand and use the systems. Water quality related GIS applications was provided to planning staff from the City of East Lansing, staff of the Tri-County Regional Planning Agency, the Flint River Watershed Coalition, Community Health Departments and participants in the Saginaw Bay watershed conference. Links to these sites include: http://elucid.iwr.msu.edu/; http://35.8.121.111/glwms/; and http://glccn.tdgrid.com/.

The IWR continued its on-line newsletter, *The Watershed Post*, an electronic newsletter that highlights current Institute activities, general interest articles, and announcement of events.

Lake and Stream Leaders Institute (LSLI)
This fiscal year, the Lake and Stream Leaders Institute offered an alumni session for previous graduates of the five day course. Alumni were invited to attend the state's Michigan Clean Water Monitoring Program annual meeting, learn what has been occurring with volunteer monitoring in lakes and streams across the state, and learn about aquatic plant identification and invasive plants. The IWR is a co-developer of the LSLI and alumni program, along with the MSU Department of Fisheries and Wildlife, MSU Extension and the nonprofit Michigan Lake and Stream Associations, Inc.

Introduction to Lakes
An Introduction to Lakes Program has been updated and revised and is currently being put into a web-based format so that the entire program can be offered online. The IWR staff worked closely with MSU Extension to implement the program by developing one of the modules and reviewing the others. In the next year, IWR will join in as an expert, and help lead on-line discussions periodically. This mode of communication and training will enable the group to reach a much broader audience, while still maintaining connectivity with participants. The actual start date is scheduled in September, 2015.

Programming with Partner Organizations
The IWR partnered with several statewide partnerships including the Michigan Natural Shoreline Partnership; Michigan Chapter, North American Lake Management Society, and the Michigan Inland Lakes Partnership to help develop conferences; factsheets; and recognition programs to associations, groups, and individuals implementing certain practices within their community or along their lake shoreline. Example programs where IWR staff took the lead or played a major role for this fiscal year included a Lunch and Learn Workshop that drew 80 people; the development of two concurrent sessions which attracted about 60 participants during the Michigan Inland Lakes Convention; the initial development of a Shoreline Recognition Program and a Technical Roundtable on natural shorelines in high energy areas, such as streams; and the development and implementation of a Student Research Grant Program, utilizing funds from one of the partner organizations.

Training
The IWR assisted with a variety of training programs and played a role in both development and in teaching portions of the programs. The IWR held training sessions on Source Water Protection and the use of the ELUCID and Great Lakes Water Management decision support systems (DSS). The Source Water program was directed towards Public Water Supply Operators, who are responsible for public drinking water supplies from groundwater sources. The DSS was directed toward conservation district and MSU Extension staff. Overall, six trainings were held for these two programs.

Online Courses
The IWR continued to offer its on-line Watershed Management Course that focuses on the watershed planning and management processes. While classes are available for academic credit, watershed planning and management professionals and lay persons can complete a set of four semesters of classes and receive a certificate in watershed management. All classes are offered year-round, and are taught by professional watershed planners, managers, and academicians. The modules include: Watershed Concepts, Unit 1. What can technology do for watershed assessment and management? Units 2&3. Basics of Physical Hydrology & Programming and Watershed Assessment Tools, Unit 4. GIS and Models. This year, IWR staff revamped and revised Unit 4. The staff also worked with undergraduate Communication students to produce an online video < http://www.iwr.msu.edu/VU/index.asp> that explained what the course was about, and how students and professionals can benefit from taking one or more of the Modules/Units. IWR staff served as trainers for the modules and worked with students on their projects and other aspects of the course.

Exhibits and Demonstrations
The University and its associated organizations hold campus events on an annual basis and request participation from departments and units. The IWR plays an active role and helped present programs for the following events: Ag Expo, a 3-day event where over 1,000 people learned about the IWR decision support systems; the MSU Science Festival, where IWR presented sessions for junior high school students; the Children's Water Festival for fifth graders where IWR held six classes teaching students about surface and groundwater; Grandparents' University for Grandparents and Youth, where IWR held two classes on water quality and indicators; Autumn Fest, where nearly 500 people visited the IWR exhibit area; and the annual

FFA competition event, where IWR is responsible for running the water quality portion of the program.

Lectures and Seminars
Lectures in the classroom, presentations at conferences, and seminars were provided by IWR staff members throughout the year to outside groups and to Extension educators on issues relating to storm water management and LID practices, tools for addressing water-related issues; high impact targeting of areas susceptible to erosion and runoff, invasive aquatic species, wellhead protection, volunteer stream monitoring, lake and stream ecology, harmful algal blooms, and pond management. Audience size varied from 10 to over 200 participants.

In-house Contributors
The IWR's technology transfer program is under the direction of Principal Investigator Dr. Lois Wolfson, with several IWR personnel contributing to the project, including Dr. Jon Bartholic, Ruth Kline-Robach, Jeremiah Asher, James Duncan, Laura Young, Jason Piwarski, Stephanie Smith, and Yi Shi. Graduate student Shayna Petit has also contributed to the program.

Notable Achievements
Title: Water Use Advisory Council
Brief: The Water Use Advisory Council was established by the Department of Environmental Quality (DEQ) Director Dan Wyant to advise the DEQ, Department of Natural Resources, and Department of Agriculture and Rural Development on the State's Water Use Program. The Council was charged with providing advice on a number of methods and tools; advice related to water conservation; technical and compliance assistance; conflicts; monitoring; data management protocols; real world impacts of withdrawals; emerging water use categories; and outcomes and metrics for determining program success. The IWR Director and another staff member were invited by the DEQ Director to be an ex-officio and member, respectively on the Council. DEQ provided funds for a third staff member to be the official recorder at all meetings. Overall, 69 recommendations, including a charge and issue, were put forth and presented in a document in 2014 to the DEQ Director.
<http://www.michigan.gov/documents/deq/WUAC_Final_Report_12_12_14_478427_7.pdf>. According to the Council, "the work of the Water Use Advisory Council is essentially the first systematic assessment and adjustment of Michigan Water Use Program since its inception in 2008. As such, it will result in recommendations that will, to the extent they are adopted and implemented, result in a revised program (both structure and public/private behavior) with a corresponding effect on Michigan's water resources."
Funding Agency: Michigan Department of Environmental Quality

Citizen Monitoring of Chlorides in Drinking Water Using Newly Developed Apps and Online Mapping Program

Basic Information

Title:	Citizen Monitoring of Chlorides in Drinking Water Using Newly Developed Apps and Online Mapping Program
Project Number:	2014MI227B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	8
Research Category:	Water Quality
Focus Category:	Education, Water Quality, Models
Descriptors:	None
Principal Investigators:	Jon Bartholic, Yi Shi

Publications

1. Shi, Y., 2014. Water Resource Management Information Systems. Lecture at WorldTAP Water Management Short Course by Dr. Yi Shi. Institute of Water Research, Michigan State University September 15, 2014.
2. Shi, Y., J. Bartholic, 2014. Water Resource Management in the United States. Presentation at Michigan State University for Chinese Students Delegation organized by Department of Forestry by Dr. Yi Shi. Institute of Water Research, Michigan State University July 28, 2014.
3. Bartholic, J., Y. Shi. 2014. ELUCID for Tribal Watershed Management. Presentation at Minneapolis, MN. Presented by Dr. Jon Bartholic, Institute of Water Research, Michigan State University September 30, 2014.
4. Shi, Y., G. Peaslee. 2015. Citizen Monitoring of Chlorides in Drinking Water Using Newly Developed Apps and Online Mapping Program, WRRI Report. Institute of Water Research, Michigan State University, 9pgs.

Title: Citizen Monitoring of Chlorides in Drinking Water Using Newly Developed Apps and Online Mapping Program

Project Number: 2014MI227B
Start: 03/1/2014
End: 02/28/15 (actual)
Funding Source: USGS ("104B")
Congressional District: eighth
Research Category: Water Quality
Focus Categories: Education, Water Quality, Models
Descriptors: Chlorides, Drinking Water, Apps, Database
Primary PI: Yi Shi, Institute of Water Research, MSU

Project Class: Research

General Statement

Problem/Demand

Salt contamination of surface and ground water can come from both natural and cultural sources. Naturally, groundwater can contain salts from dissolving rocks and organic material. As groundwater is extracted by anthropogenic activity, deeper water with higher salt content can intrude into shallow ground water. Other anthropogenic sources include road salts and human and animal wastes applied to the surface. High salt concentrations in groundwater can pollute human drinking water sources, including rivers, lakes, and public and private wells. Impacts can also affect freshwater biota (Karraker et al 2008, Corsi et al. 2010). Negative impacts from salt (sodium chloride) contamination of groundwater include salty taste of water and decreased crop yields with irrigation water that has high salt concentrations. While chlorides by themselves rarely cause a human health concern, high sodium levels can impact human health, particularly in individuals with high blood pressure or heart disease.

Methodology

Ottawa County in the southwest portion of Michigan has been addressing salt water contamination for the last few years. In order to determine the extent of saltwater contamination in water wells within Ottawa County, a subset of residences using private wells, will be obtained by looking at well log records, which have been maintained since the mid-1960s. After a subset is selected, chloride test strips will be sent to homeowners who use well water as their drinking water source. By working with researchers at Hope College (also located in Ottawa County), they will be provided instructions as to how to use the strips and asked to run replicate samples over the next year. The initial samples will be measured for salinity analytically at Hope College and compared to the test strip results to provide a robust baseline result. The homeowners will then be provided with instructions for adding their data to an online database through a computer or smart phone application. The database and phone app will be created by IWR to allow the input of data. Users will be able to locate their residence on a map and add their chloride concentrations online. Once developed, this map will be available online with a request form for others not in the original sample set to take part in the study by requesting test strips and adding their chloride data to the map. In this way, a low-cost salinity study of ground water could be broadened to much larger sample sets by dissemination through local media, K-12 school systems and online media.

Problem and Research Objectives

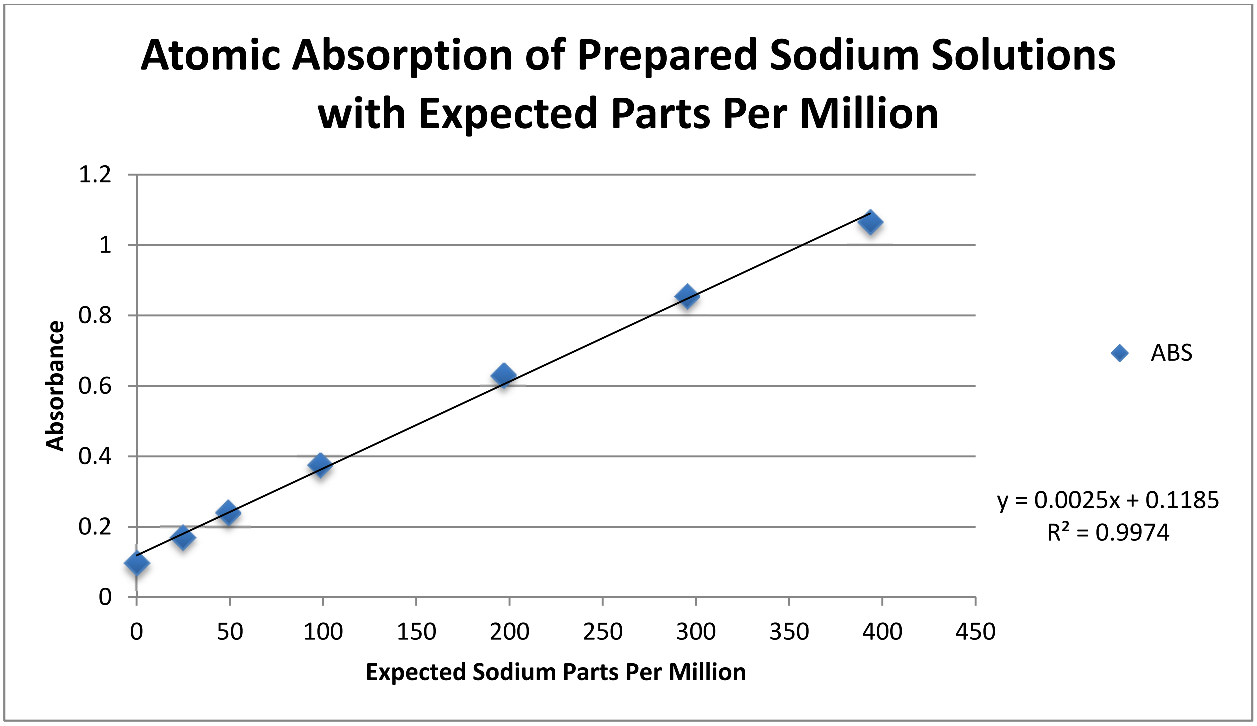
The objectives of this study are to: 1) establish a subsample of residents in Ottawa County; 2) invite them to be part of this study; 3) distribute chloride test strips with instructions for sampling their drinking water with assistance from local Hope College researchers; 4) validate the initial chloride test strip data obtained from residents analytically; 5) create an online database, mapping program, and smart phone app for adding data; 6) encourage others to obtain test strips and add their data to the map; and 7) share the information with Ottawa county officials and state agencies including the Department of Environmental Quality and Department of Transportation.

Principle Findings and Significance

Developed during this project are **mobile**/cloud based crowd sourcing procedures with latest ESRI technology to collect salinity sample data done by citizens in Ottawa County using a low cost test strip. The accuracy of the test strip is good enough and has been verified by the Hope College. Dr. Peaslee and I also held a public seminar on how to use the test strip and mobile app to collect and upload data for volunteers who are participating in this project. We are receiving new data and continuously working with volunteers when they encounter issues in the process. Some users do not have smart phone and we are informing them how to use their PC to upload their data.

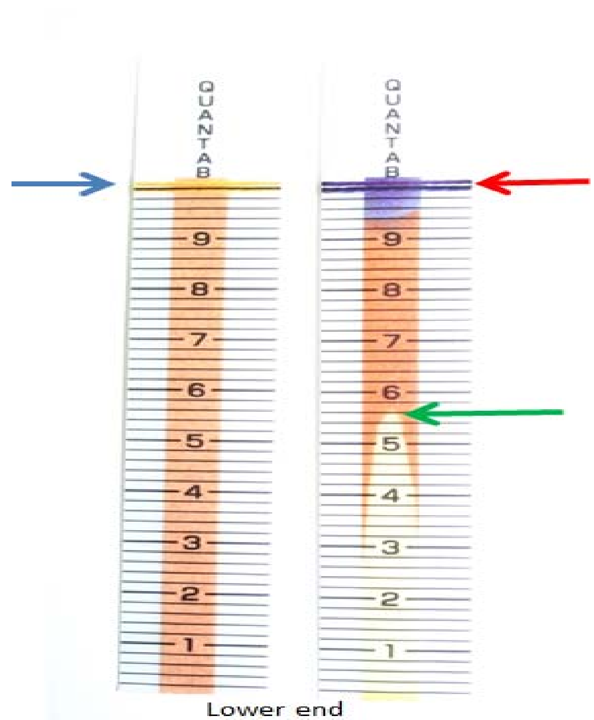
In May 2014, Yi Shi visited and described the project to me, and I showed him several locations where we were sampling in Ottawa County for sediment loading and bacterial coliform. The ground water intrusion of brine from a lower aquifer seemed like an interesting problem to study, and his method of involving citizen monitoring sounded novel and potentially scalable with low costs.

Three of my students last summer were involved in the project part time (Randall Wade, Oliver Purcell and Joshua Welsch), and they purchased and tested the chloride test strips from Hach, both on distilled water saline solutions and spiked local surface water samples. The test strips performed as advertised and the correlations with AA spectroscopy were good, and quite reproducible.



A method was written up to use the test strips in simple language, and modified after testing. The MOST recent instructions are included below.

How to use Hach's Quantab® Chloride Test Strips:



1. There will be several Quantab® test strips sealed into a single ziploc bag. Open the ziploc bag and remove one test strip at a time, and keep the remainder tightly sealed.
2. Run the well-water tap for one minute to remove any standing water from the plumbing. You can use this time to rinse a cup (or similar clean container) with water from the well. Typically, after a minute you will be dispensing fresh well water.
3. Fill a cup (or similar clean container) with fresh well water.
4. Place the lower end of the test strip into the cup of water. **This will be the end that starts with 1, 2, 3…** Do not submerge the entire test strip, be sure to keep the end labelled Quantab (with the yellow band below it) out of the water.
5. Allow the water to completely wick through the test strip, until it reaches the yellow band area. The reaction is complete when the yellow band area turns dark. This will take an additional 2 minutes or so.

6. At this point, remove the test strip from the water and dry it off with a towel or napkin. Note where the white chloride line reaches on the pre-printed scale. The higher the scale the more salinity (chloride) in the water. Take a pen and indicate this line, and write a date of sampling at the top of the test strip, and your initials/name.
7. Take a picture of this test strip with your cell phone, and upload the picture and related information to the Ottawa County Salinity Data website (described on the upload data instructions).

The next step of this project was to test the ArcGIS file upload software for both android and iphone platforms. This required getting some support to use the Hope College ArcGIS license, and to work out several bugs in the initial upload version, which Yi Shi was able to do. The students tested the applications and wrote up instructions. Unfortunately, one key step was missed which confounded users that weren't very familiar with cell phone apps, but our revision of the step-by-step instructions fixed this oversight. However, the majority of our volunteers did not make it over this hurdle the first time.

The most recent cell phone upload instructions are included here:

How to use a cell phone App (ArcGIS) to upload your data:

For iOS (Apple):

1. Go to the App Store, search "arcgis", and download the app named "ArcGIS" by ESRI. The icon should appear like the picture to the right.

2. Open the app. Once the app opens, click on the magnifying glass over the map - shown on the left above the green arrow in the figure →

3. Next, after a new screen opens, find the magnifying glass at the top right of the screen (above the red arrow). Click it and search for the map "Ottawa Chloride". The first result should be the correct map, with the description saying "This is a web map for Ottawa Chloride data collection".

4. Select the map. Once the map is selected, click the crosshair icon in the bottom right corner. Only do so while standing near the sample collection site, since this icon determines the device's current location.

5. Once your GPS location has been determined, click the wrench icon at the top of the screen, then click “collect”. After that select “Ottawa CL Data Point”. This will navigate to a screen with prompts for information to be entered. Fill out this information by typing in information for the different prompts, then select “done” in the top right corner. For example, to enter in a street address, select the words “Street Address”, enter in an address, and then click “done”. Continue with this process to answer all the prompts for information.

6. After this information is entered, select the paperclip icon at the bottom. Then click “add” and then select “Take Photo or Video”. Then take a photo of the Quantab test strip. This picture should be a well-focused close-up with the entire strip should be included. For the picture, the Quantab strip should be placed against a white background, such as a blank piece of paper (the blank space on the back of this letter). An example is shown on the right.

7. Once a usable picture has been taken, select “use photo” at the bottom of the screen. Then select “done” in the top left of the screen. This will navigate to the page with the entered data. Now select the icon next to the paper clip, that looks like a half-completed square, as seen in the picture on the left. This will navigate to a map with a blue dot in the center, showing the current location. Tap the middle of the blue dot, zooming in if needed. Then click “accept” at the top right, if the point is at the center of the dot. After that, select “done” in the top right. This will add the point to the “Ottawa Chloride” map.

For Android phones:

1. Go to the Google Play Store, search for “arcgis”, and download the app named “ArcGIS” by ESRI. The icon should appear like the picture to the right.

2. Open the app. Once the app opens, click on the magnifying glass over the map - shown on the left above the green arrow in the figure →

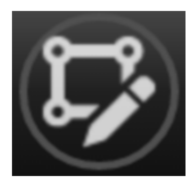
3. Next, after a new screen opens, find the magnifying glass at the top right of the screen (above the red arrow). Click it and search for the map “Ottawa Chloride”. The first result should be the correct map, with the description saying “This is a web map for Ottawa Chloride data collection”.

4. Select the map. Once the map is selected, select “open” in the top left. This will open up the map. Now select the crosshair icon in the top right. Only do so while standing near the sample collection site, since this icon determines the device’s current location.

5. Once the GPS location has been determined, select the pencil icon at the top of the screen. The icon looks like the picture to the right. This should bring up a window that says “Choose a Feature Type”. Choose the type “Ottawa CL Data Point” and tap it. This will navigate to a screen with prompts for information to be entered. Fill out this information by typing in information for the different prompts. For example, to enter in a street address, select the words “Street Address”, enter in an address, and then click “done”. Continue with this process to answer all the prompts for information.

6. Once the information is entered, select the icon that looks like a paper with a paperclip on it, as the picture on the right. Then choose to add attachment from the camera. Now take a photo of the Quantab strip. This picture should be a well-focused close-up with the entire strip should be included. For the picture, the Quantab strip should be placed against a white background, such as a blank piece of paper (the blank space on back of this letter). An example is shown on the right.

7. Once a usable picture has been taken, select the check mark in the bottom of the screen. Now select the icon shown to the left, and this will navigate back to the map. Then select the blue dot that shows the device’s current location. Zoom in to select the blue dot as accurately as possible. Then select the check mark in the top right corner. This will add the data point to the map.



After this was completed and tested locally, we began the process of finding a suitable set of test volunteers in Ottawa County. This was a two-pronged approach, and both yielded interesting information. It turns out that there is a lot of historical well testing records kept in the Ottawa County Health Department records, and with the permission of Adaline Hambley, my students spent several weeks collecting the paper copies of well records that had salinity and well depth and date of collection information recorded.

On a separate attachment is an excel spreadsheet with ~ 192 well records that might students were able to pull out at the rate of approximately 10-15 records per person per hour of searching and spreadsheet entry. It was mind-numbing work, but since there are ~390 records per file drawer and there are ~125 drawers of relevant files in the health department, there are approximately 48,750 files that could be processed. Out of these files, approximately 40% will have the full well data that is sought. That means that there are about ~19,500 files total with relevant Cl data. This was an attractive cache of data to Yi, but neither Ottawa County nor Hope College had the resources to fund this transcription of data at this time, which we estimate to be ~1200 – 1300 hours of work. Ottawa County does plan to computerize old paper records at some point in the future, but that date is uncertain.

So, we also pursued an alternate list of well owners that were being contacted by a separate IWR study with Aaron Bodbyl-Mast, which are entered as a separate tab of 150 names on the attached spreadsheet. An email was sent to this list of potential volunteers and an informational meeting was scheduled and held December 15th at the Allendale public library. 24 people responded, and about half of them showed up to the informational meeting that I ran, and Yi drove over to attend.

This list of ~24 volunteers is attached as a separate volunteer list spreadsheet. At the meeting the goals and motivation of the project were reviewed, and the test strips and cell phone upload demonstrated, and hardcopy instructions were handed out, together with Ziploc baggies of test strips. For those that weren't able to attend the informational meeting, instructions and test strips were mailed to the volunteers. The cover letter I used is attached below.

Dear Ottawa County Well Owner,

As you may know, salinity levels in groundwater are crucial measurements to make that help to determine the overall health of the groundwater recharge rates – which directly affect the users of groundwater around the state. As part of an on-going well water study funded by the US Geological Survey through the Institute for Water Resources at Michigan State University, we are seeking some volunteers to test a new method of tracking ground-water salinity levels in Ottawa County. Traditionally these measurements are made by trained well technicians who must visit each well to collect a water sample for subsequent laboratory analysis. In this experiment, we would like to provide volunteers with simple salinity "test strips", which are low-cost salinity measurement devices on a strip of plastic, and have you measure your own salinity levels three times over the next year. Instead of collecting water samples for a central laboratory, the salinity test is now robust enough that we believe citizens can make their own measurements, and simply use a cell-phone camera and downloadable App, to upload the results to a central data collection website. We have tested this process in the laboratory, and it works well, so our next step is to test the process over the next year in the field with several volunteers.

If you would be willing to participate in this experiment, please contact Dr. Graham Peaslee at Hope College (a local partner in this experiment) at the following email address: peaslee@hope.edu. He will send you an envelope that contains 4 test strips, and two sets of instructions about how to make a measurement of your well water salinity, and how to upload a photo of the results to a cell phone App. The test itself takes only a few minutes of your time, and you will need a tap that comes from your well, without passing through a water-softener system first. If you have a water-softening system in your house, you may have to use an outside tap for sampling. We would like the test to be done when you receive the kit, and then roughly once every three months afterwards for a year. We would be happy to send an email reminder every three months. If there are any questions or problems with the cell phone App, Dr. Peaslee will be able to assist via email. Nothing needs to be mailed back, and we intend that the whole process should be pretty simple for the well owner. Of course, you would be able to see the results of your salinity test right away, and check out the county-wide map as results are uploaded. If this experiment is successful next year, then it is likely to expand state-wide in subsequent years.

Thank-you for considering this request. Please email us if you have any questions.

Dr. Graham Peaslee
Chemistry Department, Hope College
616-395-7117
peaslee@hope.edu

Dr. Yi Shi
Institute for Water Resources, MSU
517-353-3742
shiyi1@msu.edu

After the meeting, several readings were made and uploaded, and are available for view at:

https://msugis.maps.arcgis.com/apps/webappviewer/index.html?id=155f2ffeafec49208a5ddc36f2950aeb

Unfortunately, in Winter months, many of the volunteers did not have access to their well water, and still others had problems with the cell phone technology or we had one individual who put the test strips in samples upsidedown. I fielded several email inquiries, and sent one reminded after a couple months, together with revised instructions on the cell phone upload, but the volunteers will need to be reminded periodically to sample. I will send another reminder to sample and upload this week.

Conclusions

I think we found several things that could work effectively as a crowd-sourced experiment to measure chloride levels. It is critical to have clear and simply instructions, and some online technical support for when cell phones don't work to their owner's expectation. The test strips work well and are simple to use and quite reliable. I don't know how much effort is required on the data collection end to turn the submitted data into a usable format, but it seems like a relatively inexpensive method to generate new salinity data rapidly.

As a result of this study, further use of the "***Citizen Monitoring of Chlorides in Drinking Water Using Newly Developed Apps and Online Mapping Program***" will be more widely utilized. The new applications will utilize the suggestions resulting from this project.

Publications

Shi, Y., 2014. Water Resource Management Information Systems. Lecture at WorldTAP Water Management Short Course by Dr. Yi Shi. Institute of Water Research, Michigan State University September 15, 2014.

Shi, Y., J. Bartholic, 2014. Water Resource Management in the United States. Presentation at Michigan State University for Chinese Students Delegation organized by Department of Forestry by Dr. Yi Shi. Institute of Water Research, Michigan State University July 28, 2014.

Bartholic, J., Y. Shi. 2014. ELUCID for Tribal Watershed Management. Presentation at Minneapolis, MN. Presented by Dr. Jon Bartholic, Institute of Water Research, Michigan State University September 30, 2014.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	2	0	0	0	2
Masters	1	0	0	0	1
Ph.D.	1	0	0	0	1
Post-Doc.	2	0	0	0	2
Total	6	0	0	0	6

Notable Awards and Achievements

Title: Improving Capacity to Collect Crowdsourced Hydrologic Data through Focused Engagement and Enhanced CrowdHydrology Software

The project team initiated an extensive process with the MDEQ to lessen the burden of permitting requirements for CrowdHydrology users. It was discovered after the user workshops that permits are required in Michigan for staff gages. After initial meetings with the department, it was determined that the gages could not be exempted from the permitting requirement without legislation. The project team worked with the MDEQ to assess alternatives such as statewide permits, and ultimately determined that having local organizations (e.g., watershed, conservation or municipal groups) lump multiple gages under one permit by watershed was the best solution. A template application was developed by the project team that contained pre-filled sections on the application along with a spreadsheet for listing out site-specific information for all gage locations. The MDEQ did not complete its review and approval of the prepared materials by the end of the grant period. At the time of this writing, the MDEQ is still reviewing materials. The project team will distribute all finalized documents to stakeholders involved with this project once approved.

Title: The "Great Lakes Clean Communities Network" (GLCCN)

GLCCN was awarded and featured as Website of the Month in April 2014, by the Great Lakes Information Network (GLIN) increasing visibility and awareness of our work on this project funded by the Great Lakes Protection Fund. http://www.great-lakes.net/news/sotm/2014.html